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Supplement to EPA Outer Continental Shelf (OCS) Operating Permit Application

Shell Beaufort Sea, Alaska Exploratory Drilling Program: Conical Drilling Unit Kulluk

PREPARED FOR:
SHELL OFFSHORE INC.

PROJECT NO. 180-20-4
FEBRUARY 28, 2011

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ABBREVIATIONS AND ACRONYMS

AAAQS	Alaska Ambient Air Quality Standards
AQCR	Air Quality Control Region
BOEMRE	Bureau of Ocean Energy Management, Regulation and Enforcement
BOP	Blowout Preventer
BPIP	Building Profile Input Program
BPX	BP Exploration, Inc.
CDPF	Catalyzed Diesel Particulate Filter
CDU	Conical Drilling Unit
CFR	Code of Federal Regulations
CH_4	Methane
CO	Carbon Monoxide
CO_2	Carbon Dioxide
CO_2e	Carbon Dioxide Equivalent
COA	Corresponding Onshore Area
DP	Dynamic Positioning
EPA	Environmental Protection Agency
EPs	Exploration Plans
GHG	Greenhouse Gases
g/kW-hr	grams per kilowatt-hour
HAP	Hazardous Air Pollutant
hp	horsepower
HPU	Hydraulic Power Units
IC	Internal Combustion
km	kilometers
kts	knots
kW	kilowatt
MLC	Mud-line Cellar
mph	miles per hour
m/s	meter per second
O_3	Ozone
OCS	Outer Continental Shelf
OCSLA	Outer Continental Shelf Lands Act
OCD	Offshore and Coastal Dispersion
OLM	Ozone Limiting Method
ORLs	Owner Requested Limits
OSR	Oil Spill Response

ABBREVIATIONS AND ACRONYMS- Continued

N_2O	Nitrous Oxide
NAAQS	National Ambient Air Quality Standards
NH_3	Ammonia
NO	Nitric Oxide
NO_2	Nitrogen Dioxide
NOAA	National Oceanic and Atmospheric Administration
NOx	Nitrogen Oxides
NSPS	New Source Performance Standards
NSR	New Source Review
PM	Particulate Matter
$PM_{2.5}$	Particulate Matter with an Aerodynamic Diameter less than 2.5 Microns
PM_{10}	Particulate Matter with an Aerodynamic Diameter less than 10 Microns
ppb	parts per billion
ppm	parts per million
PSD	Prevention of Significant Deterioration
PTE	Potential to Emit
PVMRM	Plume Volume Molar Ratio Method
R10	Region 10
ROV	Remote-operated Vehicle
RSCs	Reduced Sulfur Compounds
SCR	Selective Catalytic Reduction
SEPCO	Shell Exploration and Production Company
SO_2	Sulfur Dioxide
ULSD	Ultra-low Sulfur Diesel
USCG	U.S. Coast Guard
VOC	Volatile Organic Compounds

SECTION 1

INTRODUCTION

Shell Offshore Inc. (Shell) proposes to conduct exploratory drilling using the *Conical Drilling Unit (CDU) Kulluk (Kulluk)* on the Outer Continental Shelf (OCS) in the Beaufort Sea, Alaska. A photograph of the *Kulluk*, an ice Class IV vessel designed for operation in the arctic environment, is provided in Figure 1-1, and lease block locations relevant to this application are shown in Figure 1-2. These leases are beyond the Alaska seaward boundary, which is three miles out from the shoreline, and are therefore administered for air permitting by Environmental Protection Agency (EPA) under the OCS air regulations in 40 CFR Part 55. This application seeks authority to operate on all OCS leases currently issued in the Beaufort Sea regardless of lease ownership.

Shell modeled the drilling seasons to begin in July and end November 30. However, Shell will end all critical drilling operations no later than October 31. Within this timeframe of July through November, the *Kulluk* could be an "OCS source" for a total of 120 days. At the earliest, drilling is planned to begin in July 2012 and will continue seasonally until subsurface resources are adequately defined.

The proposed program will minimize air quality impacts by employing selective catalytic reduction (SCR) and oxidation catalyst emissions control technology. Specifically, SCR will be used to control Nitrogen Oxides (NOx) emissions from the *Kulluk's* primary generators, as well as from the propulsion engines of the two ice management vessels. The *Kulluk's* primary generators will also have oxidation catalysts installed to control emissions of Particulate Matter with an aerodynamic diameter less than 2.5 microns ($PM_{2.5}$), Volatile Organic Compounds (VOC), and Carbon Monoxide (CO). In addition, Shell is committing to purchasing only ultra-low sulfur diesel fuel (ULSD) for the project, which will practically eliminate Sulfur Dioxide (SO_2) emissions.

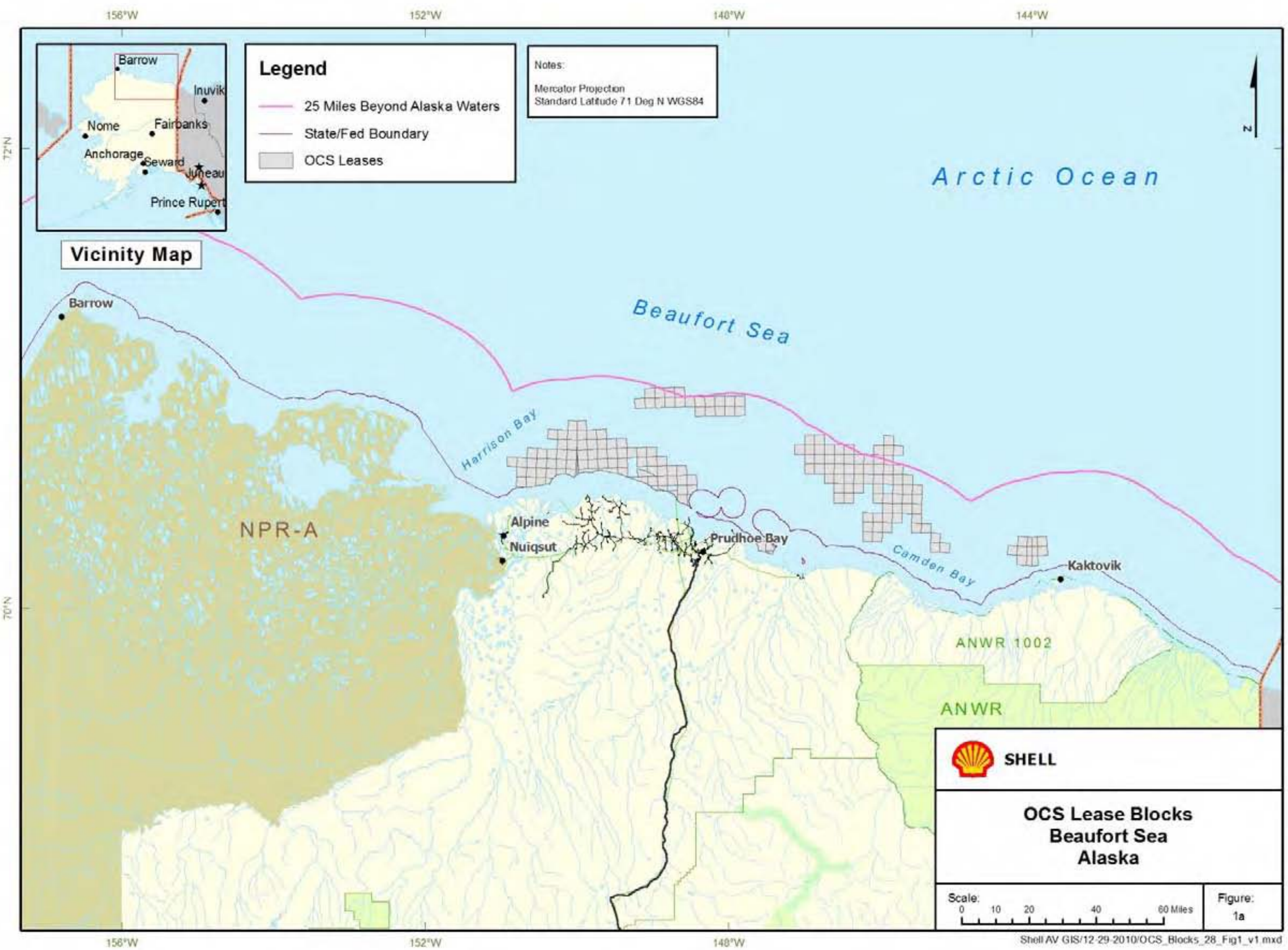
The OCS air regulations distinguish between OCS sources located within 25 miles of a state's seaward boundary and those located beyond 25 miles of a state's seaward boundary. The latter are subject to federal requirements described in Section 5.13 of the OCS air regulations. The former are subject to the requirements that would apply if they were located in the "corresponding onshore area (COA)" (section 55.14). The COA in this case is the "Northern Alaska Intrastate Air Quality Control Region (AQCR)" listed under Alaska rules 18 AAC 50.015(c). The COA rules are contained in Alaska Regulations 18 AAC 50 and include Alaska new source review requirements. Most of the Beaufort Sea leases are within 25 miles of Alaska's seaward boundary, and so are subject to federal and COA requirements. The leases located beyond this line are subject only to the federal requirements.

This operating permit application demonstrates that the proposed *Kulluk* project will comply with the National Ambient Air Quality Standards (NAAQS), as well as the Alaska Ambient Air Quality Standards (AAAQS) for ambient Ammonia (NH_3) and Reduced Sulfur Compounds (RSCs). Regarding emission restrictions, there are 4 types of emission units to which the 40 CFR Part 60 (NSPS) are applicable, the *Kulluk* compression-ignition internal-combustion engines; boilers; incinerators; and fuel tanks. No types of emission units are captured by the 40 CFR Part 61 rules. The Alaska rules 18 AAC 50 place limits on some of the *Kulluk* emission units: Part 50.050(a) limits incinerator opacity and Part 50.055 limits fuel-burning emission unit opacity, Particulate Matter (PM) and SO_2 emissions.

In accordance with the OCS air regulations (Section 55.4), Shell submitted a Notice of Intent to apply for a permit by letter to Region 10 (R10) (Natasha Greaves) dated December 10, 2010. Shell submitted an impact modeling protocol to R10 (Herman Wong) on January 20, 2011.

Figure 1-1: CDU Kulluk

Figure 1-2: Beaufort Sea Lease Block Locations



SECTION 2

PROJECT DESCRIPTION AND DEVELOPMENT OF EMISSIONS

2.1 The OCS Source

The OCS air regulations define "OCS source" as:

> [A]ny equipment, activity, or facility which: (1) Emits or has the potential to emit any air pollutant; (2) Is regulated or authorized under the Outer Continental Shelf Lands Act ("OCSLA") (43 U.S.C. §1331 et seq.); and (3) Is located on the OCS or in or on waters above the OCS. This definition shall include vessels only when they are: (1) Permanently or temporarily attached to the seabed and erected thereon and used for the purpose of exploring, developing or producing resources therefrom, within the meaning of section 4(a)(1) of OCSLA (43 U.S.C. §1331 et seq.); or (2) Physically attached to an OCS facility, in which case only the stationary sources aspects of the vessels will be regulated.

40 CFR Part 55.2. Shell believes that to give effect to the definition's "erected thereon" criterion, a floating drilling unit such as the *Kulluk* cannot become an OCS source until it is sufficiently stabilized to begin exploratory drilling operations. In other words, while the unit may be "attached" to the seabed after it has placed the normal ship's anchor, Shell does not believe that it is "erected thereon" - or for that matter "used for the purpose of exploring … resources therefrom" - until additional stabilizing anchors are placed. Nonetheless, Shell recognizes that the question of when an exploratory drilling vessel becomes an OCS source is the subject of current dispute.

In order to avoid potential delay based on the OCS source definition, Shell is, for purposes of this proposal, willing to accept the most conservative reading of the definition possible. In the future, Shell expects to seek a more reasonable approach. But for current purposes, this application assumes that the *Kulluk* becomes an OCS source when the normal ship's anchor (the first anchor placed) grips into the sea floor when the *Kulluk* is at a location for the purpose of drilling, and remains an OCS source until the last anchor (also the normal ship's anchor) is disengaged from the sea floor. This represents the first to last moment that the *Kulluk* could be considered attached to the seabed.

2.2 The Associated Vessels

During exploratory drilling operations, a fleet of associated vessels will support the *Kulluk*. These will include: (1) a primary ice management vessel; (2) a secondary ice management vessel, which will also serve as the tow vessel and anchor handler; (3) an oil spill response (OSR) vessel carrying and managing smaller work boats; (4) a possible quartering vessel for quartering of personnel; and (5) a re-supply vessel and waste removal barge or vessel. These vessels will not be part of the OCS source because they will not be "permanently or temporarily attached to the seabed and erected thereon and used for the purpose of exploring, developing or producing resources therefrom" or "physically attached to an OCS facility."

The OCS air regulations do, however, require that emissions from vessels servicing or associated with an OCS source be included in the "potential to emit" for that source while enroute to or from the source when within 25 miles of the source. 40 CFR 55.2. The potential emissions from the *Kulluk* OCS source and associated vessels when within 25 miles of the *Kulluk*, therefore are included the analysis of possible ambient impacts, as well as the "potential to emit" calculations. For a majority of the time, the two ice management vessels are expected to be beyond the 25-mile radius of the *Kulluk*, and for nearly all the time the resupply vessels will be outside the 25-mile radius of the *Kulluk.* There may be other vessels associated with the drilling project, such as a fuel tanker that will remain at a greater distance than 25 miles from the *Kulluk*, and their emissions will not contribute to either the source categorization or the impacts around the *Kulluk*. Once the *Kulluk* begins drilling and for the entire time it is drilling, the OSR vessel and possible quartering vessel are to be in place near the *Kulluk*.

2.3 The Scope of the Source for New Source Review Purposes

As discussed further in Section 2.5.2 below, potential emissions of $PM_{2.5}$, Particulate Matter with an aerodynamic diameter less than 10 Microns (PM_{10}), CO and SO_2 are all well below the 250-ton-per-year Prevention of Significant Deterioration (PSD) major source thresholds, making the *Kulluk* a minor source for these parameters. This application requests two additional limits to ensure that potential NOx emissions from the project will also remain below the major source threshold, making it a minor source for NOx as well. In addition, hazardous air pollutant (HAP) emissions will be below the thresholds for major HAP source categorization, and greenhouse gases (GHG) will be below the major source threshold of 100,000 tons per year.

This application is based on the conclusion that the stationary source subject to permitting is the *Kulluk* OCS source alone. The fact that Shell is also in the process of obtaining permits to operate the *Frontier Discoverer* drilling vessel in the Beaufort Sea does raise the question as to the scope of the stationary source. Shell recognizes that a recurring question in the oil and gas operations context is whether emissions from certain operations should be "aggregated" for new source review applicability purposes. As discussed below, Shell believes that simultaneous but separate *Kulluk* and *Discoverer* drilling operations in the Beaufort Sea would not support aggregating emissions from the two operations; they would be separate stationary sources. But in the interest of avoiding potential for delay associated with a controversial issue, Shell will, for purposes of this application, accept a restriction that ensures that emissions from the two sources cannot be aggregated for New Source Review (NSR) applicability purposes. Specifically, Shell will accept a condition in the *Kulluk* operating permit stating that Shell cannot operate the *Kulluk* as an OCS source in the Beaufort Sea in any season during which another Shell-permitted drill vessel operates as an OCS source in the Beaufort Sea.

The following discussion provides context for why this commitment means there will be no basis for aggregating emissions from the proposed *Kulluk* project with those of any other Shell operation. Shell provided Region 10 with a detailed analysis of existing case-by-case determinations and recommendation letters that address the stationary source definition adjacency criterion in a December 21, 2010 "Shell Position Paper". The paper explained why a permit condition prohibiting the *Kulluk* OCS source from drilling within three miles of the *Discoverer* OCS source would ensure that the *Kulluk* is a separate stationary source. As discussed in that paper, in all cases addressed by EPA in direct determinations or recommendations to states, significant functional interdependence was necessary to find two facilities located more than a mile apart to be "adjacent".

This conclusion was confirmed recently by the EPA Administrator in an order issued February 2, 2011 (Order Denying Petition for Objection to Permit, *In the Matter or Anadarko Petroleum Corp., Frederick Compressor Station*). The order highlights the lack of "dedicated relationship" between noncontiguous activities under common control necessary to make them adjacent. Even if the *Kulluk* and *Discoverer* OCS sources operated in the same sea at the same time, they would not have the type of dedicated relationship that EPA has found necessary to make two noncontiguous activities "adjacent". Each drilling unit will have its own associated fleet and therefore ability to operate fully independent of the other. Shell notes that a statement in the OCS air regulations preamble reflects EPA's assumption that even if the two units shared a resupply vessel, it would not make otherwise separate OCS sources adjacent. EPA stated that "[e]missions from vessels that service more than one OCS facility will be allocated among all the OCS facilities that the vessel services, to ensure there will be no double counting of emissions". 57 Fed. Reg. 40792, 40794 (Sept. 4, 1992). EPA would not direct emissions allocation between OCS sources if it viewed sharing service vessels as creating a single source.

Despite its confidence that a three-mile restriction would ensure that the *Kulluk* remains a separate stationary source, Shell recognizes that there are no bright legal lines in this area, which can lead to uncertainty. And uncertainty can result in delay. Therefore, for purposes of this application, Shell is accepting a restriction that is significantly more stringent than three-miles. For future permitting, Shell hopes to work with the Agency to define reasonable and defensible restrictions to ensure that noncontiguous activities under common control are not considered adjacent. In other words, Shell's commitment for this permit does not set a precedent. Shell is committing to a prohibition on operating the *Kulluk* as an OCS source in any season during which another Shell-permitted drill vessel operates as an OCS source in the Beaufort Sea simply to ensure that aggregation is not a controversial issue for this permit.

This prohibition ensures that the *Kulluk* and *Discoverer* OCS sources will not be adjacent or interdependent in any way. Given the great distances between the Beaufort Sea lease blocks and the Shell lease blocks in the Chukchi, the words of the Environmental Appeals Board apply:

> Applying the phrase 'contiguous or adjacent properties' as requiring aggregation of emissions producing activities spanning hundreds of miles interspersed with vast swaths of open water that is accessible to the public would distort the ordinary meaning of "building, structure, facility, or installation" in a manner EPA did not intend when it promulgated the definition. … The phrase 'contiguous or adjacent properties' must be understood as connoting a more substantial connectedness, proximity, or continuity that would correspond to a common understanding of building, structure, facility, installation, or plant.

In Re Shell Offshore, Inc., Kulluk Drilling Unit and Frontier Discoverer Drilling Unit, OCS Appeal Nos. 07 & 07-02, Order Denying Review in Part and Remanding in Part, Sept. 14, 2007, at 384-385. Further, if the two sources cannot operate in the Beaufort Sea together in any one season, there is no possible way for their operations to be functionally interdependent. Each OCS source will fully independent and will have to rely on its own associated fleet.

2.4 A Typical Seasonal Exploratory Drilling Sequence

The *Kulluk* is a drilling platform without its own propulsion power. With the start of each drilling season on or after July 1, the *Kulluk* will be towed by the anchor handler to the location for the drilling of its first well or part of a well. When it reaches the desired drill position, the rig will lower the single normal ship's anchor. When this anchor is secure, the anchor handler will release the tow cable and the *Kulluk* will be held in place by the ship's anchor. The anchor handler will then go to the leeward side of the *Kulluk*, extend the first stabilization anchor cable, connect the high holding power anchor and lower it to the sea floor. The anchor handler deploys each anchor in a pre-determined sequence, and in this manner all 12 of its main stabilizing anchors will be placed. No other vessels are involved in the anchoring procedure. Once all the stabilization anchors are in place, they will be sequentially tensioned and once the anchors are confirmed to be holding the rig, it will be ready for drilling activity. Shell has evaluated this anchoring procedure and determined it to be safe for defined location and sea conditions. Anchor deployment/retrieval will not be attempted in rough sea states. Each anchor will take about 2.5 hours to deploy, with a total anchoring time of less than 48 hours. Retrieval of the anchors is a reversal of this placement process, with the ship's anchor being the final anchor to be lifted, at which time the tow vessel, which is also the anchor handling vessel, will connect to the *Kulluk* and tow it away. Stabilization anchor retrieval takes about the same amount of time as placement. The stabilization anchors are designed for quick release from the cables so that the *Kulluk* can be moved quickly off site in emergency situations. This might occur if unanticipated thick ice is moving toward the *Kulluk* and there is insufficient ice management capacity to deflect it. In the unlikely event that this was to occur, either the *Kulluk* would return and reconnect to the anchors or the anchor handling vessel would retrieve the anchors at a later time.

During the time of anchor placement and retrieval the *Kulluk*'s drill equipment is shut down and the anchor handler is moving around the *Kulluk* at low speed and low power. The normal anchoring is performed with the anchor handler backing up to the *Kulluk*, securing and extending the anchor cables out to approximately 800 meters, attaching the anchor, and lowering the anchors into place. There will be no drilling activity during the activities of anchor placement and retrieval so this will be a low-emission activity from both the *Kulluk* and from the associated fleet.

The drilling process involves three mutually exclusive drilling activities: (1) drilling of the mud-line cellar (MLC), (2) drilling of the well, and (3) casing, logging, and cementing. The *Kulluk* could discontinue drilling after completing the MLC or any of the stages of well drilling and cementing and logging. Once the *Kulluk* finishes its mission at a location, whether drilling to depth or only drilling the MLC, or any other portion of the well, it would raise anchors and either shut down for the season or move to the next drilling location. From a seasonal perspective, the *Kulluk* could drill as many holes as ice conditions and requested limits would allow. In seasons with the best conditions for drilling, Shell would expect the *Kulluk* to be able to complete a maximum of four wells to depth.

The *Kulluk* will need to be resupplied and have waste removed during the season and this could occur while it is an OCS source, or when it is between wells and not an OCS source. For estimation of maximum emissions, Shell assumes a maximum of 24 resupply and waste removal trips combined, for the 120-day drilling season, which is an average of one every five days. Resupply or waste removal involves transiting from outside the 25-mile radius to the *Kulluk*, loading or unloading, and transiting back out of the 25-mile area. The transits are expected to take about three hours and the loading up to a maximum of 24 hours. During this 24-hour period, the vessel would be held in position close to, but not touching, the *Kulluk* in "dynamic positioning" (DP) mode, which means that it maintain position with its propulsion engines. Waste removal could also take the form of a tug bringing a barge to the side of the *Kulluk* and the barge tying up to the *Kulluk* for an extended period of time. As a barge connected to the *Kulluk* it would become part of the OCS source, but the barge will have no emissions sources on it to be regulated. As the barge is tied to the *Kulluk*, the tug would move away and outside the 25-mile radius area from the *Kulluk*.

The ice management fleet will only be within 25 miles of the *Kulluk* when there is ice to manage or temporarily for other utility purposes, such as replacing an anchor or exchanging workers at the *Kulluk*. These temporary activities would be on the order of an hour in duration at any one location; and the vessels would be in motion most of that time. Also, as described above, the secondary ice management vessel will be used to place and retrieve anchors. The OSR vessel and possible quartering vessel would remain within about five kilometers of the *Kulluk*, generally not upwind. At times they will be anchored and when they are, their engines would be providing power primarily for lighting and other domestic purposes. The OSR vessel would engage in routine response exercises which would involve use of some of the small work boats transported on the OSR vessel.

2.5 Emissions from the Kulluk

2.5.1 Kulluk Sources

The primary *Kulluk* emissions sources are diesel engines, but also include an incinerator, boilers and heaters. The largest diesel engines drive generators which power the drill motors but also the domestic electric requirements. Other diesel engines power other drilling-related equipment, including hydraulic pumps, cranes, and emergency-related equipment. This emergency-related equipment includes an emergency generator, an emergency anchor lifting engine, lifeboat engines, a hydraulic pump for a remote-operated vehicle (ROV), diver equipment, all of which have highly intermittent use, but will need to be exercised on an infrequent scheduled cycle. The *Kulluk* emission units are grouped for permitting purposes as source groups of similar engines, each group with a maximum emission limit (pounds per day) of NOx and $PM_{2.5}$. Since SO_2 emissions are a function of the fuel quality, its emissions are limited by restricting the sulfur in the fuel. CO and VOC will be low and by limiting NOx and $PM_{2.5}$, the emissions of CO and VOC are also capped to a sufficient accuracy to guarantee acceptable impacts. All units are diesel-fueled. Tables 2-1, 2-2, and 2-3 provide listings of the source groups of the *Kulluk* (and associated fleet, which is discussed later). There are diesel fuel tanks, listed on Table 2-4, which will have negligible emissions because of the low vapor pressure of diesel fuel, especially at Arctic temperature.

As described earlier, the drilling of each well is comprised of three mutually exclusive activities: (1) the drilling of the MLC, (2) the drilling of the well, and (3) logging, cementing, and casing. The MLC (also called a top hole) is a hole about 20 feet in diameter and about 36 feet deep, created to house the well cap and blowout preventer (BOP). Drilling of the MLC involves high use of the primary generators, air compressors, and MLC Hydraulic Power Units (HPU). MLC drilling represents the activity with the highest hourly emissions from all source groups combined. Each MLC is expected to take up to five days per well.

Table 2-1: Daily Maximum Emissions for Each Source Group – MLC Activity

Source Group by Vessel	NO_X lb/day	$PM_{2.5}$ lb/day	PM_{10} lb/day	CO lb/day	SO_2 lb/day
Kulluk					
Generation	456.1	71.3	71.3	206.3	12.8
MLC HPU'S	887.8	35.5	35.5	47.9	2.6
Air compressors	710.2	14.8	14.8	42.8	2.6
Cranes	63.9	2.6	2.6	3.4	0.2
Heaters & Boilers	21.3	3.5	3.5	5.3	1.5
Seldom-used units	9.0	0.7	0.7	2.4	2.7E-02
Emergency Generator	36.6	2.9	2.9	9.9	0.1
Incinerator	5.0	23.2	27.2	496.8	4.1
Primary Ice Management					
Propulsion & Generation	2,032.8	317.6	317.6	919.6	56.8
Heaters & Boilers	35.6	5.9	5.9	8.9	2.5
Seldom-used units	6.8	0.5	0.5	1.8	2.0E-02
Incinerator	5.5	25.9	30.3	554.4	4.6
Secondary Ice Management / Anchor Handler					
Propulsion & Generation	2,032.8	317.6	317.6	919.6	56.8
Heaters & Boilers	35.6	5.9	5.9	8.9	2.5
Seldom-used units	6.8	0.5	0.5	1.8	2.0E-02
Incinerator	5.5	25.9	30.3	554.4	4.6
Resupply Ship - transport mode					
Propulsion & Generation	0.0	0.0	0.0	0.0	0.0
Seldom-used units	0.0	0.0	0.0	0.0	0.0
Resupply Ship - DP mode					
Propulsion & Generation	1,826.2	76.1	76.1	550.8	6.8
Seldom-used units	1.4	0.1	0.1	0.4	4.1E-03
OSR vessel					
Propulsion & Generation	1,065.3	44.4	44.4	321.3	4.0
Seldom-used units	6.8	0.5	0.5	1.8	2.0E-02
Incinerator	4.5	21.0	24.6	450.0	3.8
Quartering vessel					
Propulsion & Generation	1,369.7	11.4	11.4	55.1	6.8
Seldom-used units	6.8	0.5	0.5	1.8	2.0E-02
Incinerator	4.5	21.0	24.6	450.0	3.8
OSR work boats					
Work boats	257.4	20.6	20.6	69.4	0.8
TOTAL- (lb/day)	**10,894**	**1,050**	**1,070**	**5,685**	**178**
TOTAL- (lb/day)-w/o Egen	**10,600**	**1,026**	**1,046**	**5,606**	**177**

shading represents proposed requested limit to be demonstrated on a daily basis

shading represents requested limit to be demonstrated by on weekly basis

Table 2-2: Daily Maximum Emissions for Each Source Group – Drilling Activity

Source Group by Vessel	NO_X lb/day	$PM_{2.5}$ lb/day	PM_{10} lb/day	CO lb/day	SO_2 lb/day
Kulluk					
Generation	456.1	71.3	71.3	206.3	12.8
MLC HPU'S	0.0	0.0	0.0	0.0	0.0
Air compressors	0.0	0.0	0.0	0.0	0.0
Cranes	63.9	2.6	2.6	3.4	0.2
Heaters & Boilers	21.3	3.5	3.5	5.3	1.5
Seldom-used units	9.0	0.7	0.7	2.4	2.7E-02
Emergency Generator	36.6	2.9	2.9	9.9	0.1
Incinerator	5.0	23.2	27.2	496.8	4.1
Primary Ice Management					
Propulsion & Generation	2,032.8	317.6	317.6	919.6	56.8
Heaters & Boilers	35.6	5.9	5.9	8.9	2.5
Seldom-used units	6.8	0.5	0.5	1.8	2.0E-02
Incinerator	5.5	25.9	30.3	554.4	4.6
Secondary Ice Management / Anchor Handler					
Propulsion & Generation	2,032.8	317.6	317.6	919.6	56.8
Heaters & Boilers	35.6	5.9	5.9	8.9	2.5
Seldom-used units	6.8	0.5	0.5	1.8	2.0E-02
Incinerator	5.5	25.9	30.3	554.4	4.6
Resupply Ship - transport mode					
Propulsion & Generation	0.0	0.0	0.0	0.0	0.0
Seldom-used units	0.0	0.0	0.0	0.0	0.0
Resupply Ship - DP mode					
Propulsion & Generation	1,826.2	76.1	76.1	550.8	6.8
Seldom-used units	1.4	0.1	0.1	0.4	4.1E-03
OSR vessel					
Propulsion & Generation	1,065.3	44.4	44.4	321.3	4.0
Seldom-used units	6.8	0.5	0.5	1.8	2.0E-02
Incinerator	4.5	21.0	24.6	450.0	3.8
Quartering vessel					
Propulsion & Generation	1,369.7	11.4	11.4	55.1	6.8
Seldom-used units	6.8	0.5	0.5	1.8	2.0E-02
Incinerator	4.5	21.0	24.6	450.0	3.8
OSR work boats					
Work boats	257.4	20.6	20.6	69.4	0.8
TOTAL- (lb/day)	**9,296**	**1,000**	**1,020**	**5,594**	**173**
TOTAL- (lb/day)-w/o Egen	**9,002**	**976**	**996**	**5,515**	**172**

shading represents proposed requested limit to be demonstrated on a daily basis

shading represents requested limit to be demonstrated by on weekly basis

Table 2-3: Daily Maximum Emissions for Each Source Group – Cementing and Logging Activity

Source Group by Vessel	NO_X lb/day	$PM_{2.5}$ lb/day	PM_{10} lb/day	CO lb/day	SO_2 lb/day
Kulluk					
Generation	322.0	50.3	50.3	145.7	9.0
MLC HPU'S	0.0	0.0	0.0	0.0	0.0
Air compressors	0.0	0.0	0.0	0.0	0.0
Cranes	106.5	4.3	4.3	5.7	0.3
Heaters & Boilers	21.3	3.5	3.5	5.3	1.5
Seldom-used units	9.0	0.7	0.7	2.4	2.7E-02
Emergency Generator	36.6	2.9	2.9	9.9	0.1
Incinerator	5.0	23.2	27.2	496.8	4.1
Primary Ice Management					
Propulsion & Generation	2,032.8	317.6	317.6	919.6	56.8
Heaters & Boilers	35.6	5.9	5.9	8.9	2.5
Seldom-used units	6.8	0.5	0.5	1.8	2.0E-02
Incinerator	5.5	25.9	30.3	554.4	4.6
Secondary Ice Management / Anchor Handler					
Propulsion & Generation	2,032.8	317.6	317.6	919.6	56.8
Heaters & Boilers	35.6	5.9	5.9	8.9	2.5
Seldom-used units	6.8	0.5	0.5	1.8	2.0E-02
Incinerator	5.5	25.9	30.3	554.4	4.6
Resupply Ship - transport mode					
Propulsion & Generation	0.0	0.0	0.0	0.0	0.0
Seldom-used units	0.0	0.0	0.0	0.0	0.0
Resupply Ship - DP mode					
Propulsion & Generation	1,826.2	76.1	76.1	550.8	6.8
Seldom-used units	1.4	0.1	0.1	0.4	4.1E-03
OSR vessel					
Propulsion & Generation	1,065.3	44.4	44.4	321.3	4.0
Seldom-used units	6.8	0.5	0.5	1.8	2.0E-02
Incinerator	4.5	21.0	24.6	450.0	3.8
Quartering vessel					
Propulsion & Generation	1,369.7	11.4	11.4	55.1	6.8
Seldom-used units	6.8	0.5	0.5	1.8	2.0E-02
Incinerator	4.5	21.0	24.6	450.0	3.8
OSR work boats					
Work boats	257.4	20.6	20.6	69.4	0.8
TOTAL- (lb/day)	**9,204**	**980**	**1,000**	**5,536**	**169**
TOTAL- (lb/day)-w/o Egen	**8,910**	**957**	**977**	**5,457**	**168**

shading represents proposed requested limit to be demonstrated on a daily basis

shading represents requested limit to be demonstrated by on weekly basis

Table 2-4: Kulluk Diesel Fuel Tanks

Tanks	Capacity	Unit
Fuel Tank A	680	cubic meters
Fuel Tank B	676	cubic meters
Fuel Tank C	247	cubic meters

Well drilling is expected to consist of drilling a 36-inch-diameter hole to the required interval and setting 30-inch-diameter steel casing, which is cemented in place to prevent fluid migration through the annular area to the surface. The top of the 30-inch casing (bottom of the MLC) has a guide base with receptacles for guidelines that facilitate reentry into the well. Well drilling activity involves a high use of the primary generators but not the air compressors or MLC HPUs and is the second highest hourly emission activity. The drilling of the well, below the MLC, is expected to take up to an additional 12 days per well.

Up to an additional 13 days per well can be consumed in the logging, cementing, and casing of the well. These activities can occur intermittently while on location and represent the lowest hourly emission activity scenario. If wells are drilled to depth, Shell anticipates a maximum of four wells per season for a total of 120 days as an OCS source. Although each well is anticipated to consume up to about 30 days (5 days for MLC plus 12 days for drilling, plus 13 days for all other non-drilling activities), the *Kulluk* could complete a well in a shorter period of time and drill until the 120-day season is consumed. For demonstration of compliance with ambient standards, the platform is assumed to be left at a single well site for the full 120-day season.

Cranes are used intermittently throughout the three drilling activities, although they will be used more during logging, cementing, and casing because of the need to move casing and other equipment into place. There are multiple operational limits on the cranes that keep the engines from operating at rated power. The boom lifting capacity limits the engines to approximately 60 percent of nameplate power. Moreover, the nature of crane operation is that it lifts or swings only for very short periods (minutes) and idles for long periods of time while being loaded and unloaded. Normally there will be one crane operated at a time on the *Kulluk* although infrequently there may be times that two of the three cranes will operate simultaneously. The requested limits for Internal Combustion (IC) engines (the pound per day limits shown in Tables 2-1, 2-2 and 2-3) will limit crane use to much less than three cranes operating simultaneously at nameplate engine ratings. The boilers are used for heating and only one is intended for use at any time, although the emissions and impacts are estimated assuming that both are operating continually at nameplate capacity.

2.5.2 Requested Limits

As part of this application, Shell requests that the operating permit for the *Kulluk* project impose several additional limits. In some places, this application refers to these limits as "Owner Requested Limits" or "ORLs". Shell recognizes that this phrase has specific meaning under Alaska regulations, but as used in this application, intends it to refer to the requested limits in both the state and federal contexts.

These requested limits will effectively limit ambient air impacts of emissions from the *Kulluk* and associated vessels. In addition, two of the requested limits - the limit on hours of each of the three drilling activities and limiting NOx emissions to less than 250 tons per year (measured on a rolling weekly basis) - also ensure that the *Kulluk* remains a minor source. These two requested limits are also considered "Owner Requested Limits" under Part 50.225 of the Alaska air regulations because they are for the purpose of avoiding source classifications, such as PSD. Shell believes that the specific data required under 50.225(b) are provided within the application.

The requested limits are summarized in Table 2-5; details on the limits, including proposed compliance and monitoring methods, are provided in the I-COMP forms. Among the requested limits is a commitment to purchase only ULSD which limits the sulfur in the fuel to under 100 parts per million (ppm) and practically eliminates SO_2 emissions. ULSD is not available in Alaska and needs to be barged from outside the Alaska area. Shell agrees to purchase ULSD for the *Kulluk* and associated fleet. To limit the annual potential emissions and the frequency of high short-term potential emissions, Shell proposes ORLs to limit OCS source activities to 2,880 hours (120 days) per season, to limit MLC drilling to 480 hours (20 days) of that 120-day season, and to limit combined MLC and drilling to 1,632 hours (68 days) of that 120-day season. Shell also proposes to limit each source group's potential emissions of NOx and PM. These ORLs are shown as shaded values on Tables 2-1, 2-2, 2-3, and on Table 2-5. For all of the source groups (except incinerator and seldom-used sources) Shell proposes to demonstrate compliance with the potential emission limit by monitoring daily fuel consumption (gallons per day) and applying it to the demonstrated source group emission factor (pound per gallon). The *Kulluk* incinerator is intended for disposal of non-hazardous domestic and industrial waste. It is to be limited in operation by ORL to 12 hours of use, during the daytime, expected to be 8 a.m. to 8 p.m. During that time it could operate at capacity. Compliance for the incinerator would be tracked through recording of the time it is operated over each day applied to capacity emission factors (pound per hour). The measuring of daily fuel consumption and operating time are simple, accurate and effective ways to track compliance.

Table 2-5: Summary of Requested Restrictions

Owner Requested Limit (ORL)	Value
MLC drilling	480 hours per season (20 days)
MLC and well drilling combined	1,632 hours per season (68 days)
All OCS source activities combined	2,880 hours per season (120 days)
Number of resupply/waste removal trips	24 per season
Kulluk incinerator	12 hours per day, 8 a.m. through 8 p.m.
Fuel Sulfur content – Kulluk and Fleet	Purchase ULSD, less than 0.01% during use
All IC engine and heater groups	A set of emission limits (lb/day) for each pollutant, highlighted in Tables 2-1, 2-2, and 2-3.
Annual NOx emissions for Kulluk and Fleet	Less than 250 tons per year

There are multiple emergency and small source units, including life-boat propulsion engines, diver emergency air compressors, and a larger emergency generator. These exist for emergency purposes and are not planned to be used, but they need short and infrequent exercising. This engine exercising results in very minor emissions from each emission unit, and exercising the individual unit emissions will be spaced throughout a weekly or longer period. In other words, the units will not be exercised simultaneously, but will be relatively randomly spaced over at least a two-week or longer period of time. Therefore an ORL of total emissions from these sources, and demonstrated on a weekly time frame, is both practical and reasonable. Compliance with this will be based on a small-engine set of emission factors and tracked through weekly fuel consumption. (For impact modeling purposes, the larger emergency generator emissions are broken out of the seldom-used source allowance and modeled as a 2-hour emission occurrence once every 30 days, consistent with the U.S. Coast Guard (USCG) emergency generator exercising requirements.)

To ensure that the proposal remains a minor source for NOx, Shell requests a condition limiting NOx emissions to less than 250 tons per year, to be demonstrated on a weekly rolling annual total basis. The NOx emissions from the *Kulluk* and the ancillary vessels (when within 25 miles of the *Kulluk*) will be summed for this weekly demonstration. Table 2-6 shows that the NOx emissions summed over all of the short-term potential emission limits, assuming maximum operations for a full 120-day season would be 279 tons, but in the exploration operations context, Shell is certain that actual emissions will be below 250 tons per year and will demonstrate this on the weekly totaled annual sum of NOx emissions. From the annual emission inventory on Table 2-6, which shows all other pollutant emission rates substantially lower than NOx, Shell proposes that by demonstrating compliance with only the annual NOx emissions, all other pollutants will be well below the 250 tons per year limit and it should not be necessary to separately demonstrate this annual emission limit for any of the other regulated pollutants.

Table 2-6: Annual Maximum Emissions for Each Source Group

Source Group by Vessel	NO_X tons/year	$PM_{2.5}$ tons/year	PM_{10} tons/year	CO tons/year	SO_2 tons/year
Kulluk					
Generation	23.9	3.7	3.7	10.8	6.7E-01
MLC HPU'S	8.9	0.4	0.4	0.5	2.6E-02
Air compressors	7.1	0.1	0.1	0.4	2.6E-02
Cranes	4.9	0.2	0.2	0.3	1.5E-02
Heaters & Boilers	1.3	0.2	0.2	0.3	9.1E-02
Seldom-used units	5.4E-01	4.3E-02	4.3E-02	1.5E-01	1.6E-03
Emergency Generator	7.3E-02	5.9E-03	5.9E-03	2.0E-02	2.2E-04
Incinerator	0.3	1.4	1.6	29.8	2.5E-01
Primary Ice Management					
Propulsion & Generation	46.3	7.2	7.2	21.0	1.3E+00
Heaters & Boilers	0.8	0.1	0.1	0.2	5.7E-02
Seldom-used units	1.5E-01	1.2E-02	1.2E-02	4.2E-02	4.6E-04
Incinerator	0.1	0.6	0.7	12.6	1.1E-01
Secondary Ice Management / Anchor Handler					
Propulsion & Generation	46.3	7.2	7.2	21.0	1.3E+00
Heaters & Boilers	0.8	0.1	0.1	0.2	5.7E-02
Seldom-used units	1.5E-01	1.2E-02	1.2E-02	4.2E-02	4.6E-04
Incinerator	0.1	0.6	0.7	12.6	1.1E-01
Resupply Ship - transport mode					
Propulsion & Generation	11.0	0.5	0.5	3.3	4.1E-02
Seldom-used units	8.2E-02	6.5E-03	6.5E-03	2.2E-02	2.4E-04
Resupply Ship - DP mode					
Propulsion & Generation	21.9	0.9	0.9	6.6	8.2E-02
Seldom-used units	8.2E-02	6.5E-03	6.5E-03	2.2E-02	2.4E-04
OSR vessel					
Propulsion & Generation	38.4	1.6	1.6	11.6	1.4E-01
Seldom-used units	4.1E-01	3.3E-02	3.3E-02	1.1E-01	1.2E-03
Incinerator	0.3	1.3	1.5	27.0	2.3E-01
Quartering vessel					
Propulsion & Generation	49.3	0.4	0.4	2.0	2.5E-01
Seldom-used units	4.1E-01	3.3E-02	3.3E-02	1.1E-01	1.2E-03
Incinerator	0.3	1.3	1.5	27.0	2.3E-01
OSR work boats					
Work boats	15.4	1.2	1.2	4.2	4.6E-02
Total - Annual (120 days) without NOx Limit	**279**	**29**	**30**	**192**	**5**
Total - PTE	**<250**	**29**	**30**	**192**	**5**

Shell proposes to limit the number of resupply and/or waste removal trips to the *Kulluk* to 24 per season. Each resupply trip will consist of a vessel traveling to the *Kulluk*, going into DP mode beside the *Kulluk* for up to 24 hours when materials would be loaded or unloaded, then leaving the 25-mile radius of the *Kulluk*. If a barge is to be used, it would be brought in by tug to the side of the *Kulluk*, moored there and the tug would move away from the drilling rig. The tug would return to retrieve the barge and remove it from the 25-mile radius area. The resupply vessel and waste removal barge/tug emissions are separately capped for the transit activity and the DP activity, because they are recognized as separate activities for impact modeling purposes.

The per-source-group emission ORL limits for all of the emission units of the three separate activities (MLC drilling, well drilling, logging, casing and cementing) are shown in shading on Tables 2-1 through 2-3. The source group ORLs are in the form of emission caps per activity rather than operational restrictions on specific make and model numbers of emission units. This provides necessary flexibility in use of and types of equipment needed for drilling and vessel support, while still demonstrating compliance with the ambient standards. Shell anticipates possible change-out of engines and vessels, and alteration of use patterns as maintenance requires and as drilling practices in the Arctic are optimized.

2.5.3 Kulluk Emission Controls

The *Kulluk* will have SCR as a NOx tailpipe emission control on its primary generators. A control system vendor guarantee of 1.6 grams per kilowatt-hour (g/kW-hr) for the current 8,500 horsepower (hp) generator engines as a group defines the expected maximum NOx emission rate for the primary generators. This level of 1.6 g/kW-hr as the maximum for its NOx emission estimates will be demonstrated through stack testing. The primary generators will also have oxidation catalysts installed for control of all oxidizeable substances, including $PM_{2.5}$, VOC, and CO. A $PM_{2.5}$ emission level of 0.25 g/kW-hr is used as the maximum and will be demonstrated by stack test. CO and VOCs are expected to be controlled to 80 percent and 70 percent respectively, as estimated in the EPA emission manual, AP-42. Since there is no risk of exceeding 250 tons of either, or of violating the ambient standards for these two pollutants, no stack test should be necessary to demonstrate these efficiencies.

The other engines normally used in the drilling activities (the air compressors, the MLC HPUs, and cranes) will also have oxidation catalysts as tailpipe control for oxidizing all oxidize-able substances, including $PM_{2.5}$, VOC, and CO. AP-42 assumes engine emissions control to be 50 percent for $PM_{2.5}$, 80 percent for CO, and 70 percent for VOC.

2.5.4 Fuel Quality

Shell will purchase only ULSD fuel for use in the *Kulluk* and all of the associated fleet while the *Kulluk* is an OCS source. This fuel is produced with a sulfur content of 15 ppm by weight or less. Use of fuel of this quality for marine vessels is practically non-existent and the current infrastructure (delivery piping, barges, etc.) for delivering this fuel is not capable of maintaining the ULSD quality because of contamination from previously loaded fuel with higher levels of sulfur. For this reason, although Shell commits to purchasing only ULSD and making a good-faith effort to ensure delivery of minimum-sulfur fuel, but Shell requests a permissible test limit of 100 ppm sulfur in the fuel consumed by the *Kulluk* and associated fleet.

2.5.5 Estimation of Emissions

Emissions for each source group are estimated using emission unit nameplate outputs, adjusted by system limits and ORLs, then applying appropriate emission factors and tailpipe control efficiencies. These emission factors are taken from existing stack test information or manufacturers' stated emission factors (for the larger sources) and from EPA's AP-42 manual (for the small sources and pollutants of lower importance). These represent maximum expected emissions and Shell will meet these maximum estimated emissions on a daily basis (weekly basis for the seldom-used source group). The currently anticipated daily emissions are shown in Tables 2-1, 2-2, and 2-3 and represent the short-term anticipated potential to emit (PTE) for the source groups. All the assumptions built into the calculation of emissions of all the emission groups are listed on the spreadsheets in Attachment A. Emissions for compliance monitoring purposes will be calculated by tracking fuel consumption for the combustion sources and hours of operation for the incinerator and applying the appropriate emission factors.

Except for the incinerator, the maximum hourly emissions of all non-emergency sources are calculated as the 24-hour maximum emissions divided equally into 24 hours. This is a reasonable assumption for the *Kulluk* source groups because the 24-hour emissions are also hourly system limits. It may appear that for the cranes there could be higher individual hourly emissions. In fact, since there is normally only one crane operator and three cranes operated 30 percent of the time, that crane operator would need to operate one crane nearly the entire day to operate each 30 percent of the time. Thus the emissions are spread relatively evenly throughout the 24-hour day. So the 24-hour maximum emission rates are reasonable representations of the hourly maximum rates. The *Kulluk* incinerator is limited by ORL to 12 hours of operation, between 8 a.m. and 8 p.m., and its emissions are calculated at nameplate capacity for those 12 hours.

The seldom-used source group is to be tracked on a weekly basis as discussed above. The emissions from these will be totaled over the week period (168 hours). The only large engine of these seldom-used engines is the emergency generator at 650 kilowatt (kW) rating, which is exercised for two hours per month. To account for the generator emissions in the modeling analysis, the emergency generator is run at maximum output for two hours each 30-day period. During these two hours the generator has potential emissions of 18.3 pounds NO_x per hour (at current emission factor this is equivalent to 38 gallons per hour) per 30-day period, for a total of 77 gallons per 30-day period. Then the remaining allowable emissions, which are from several small engines, running at undefined times, are evenly spread over the 30-day period. The weekly emissions are equal to the total weekly for seldom-used sources minus the weekly component assigned to the once-per-30-day emergency generator exercising (18 gallons per week).

With tailpipe emission controls, there could be a concern with emissions during startup and shutdown when the emission control is not fully effective. In the case of the *Kulluk* and associated fleet, the anticipated control devices are oxidation catalysts and selective catalytic reduction on the primary generators (and ice management fleet propulsion engines). These source groups with SCR control will have started up to some operating level before the *Kulluk* becomes an OCS source or they have entered to 25-mile radius region and will be operational at some power level throughout the entire time as an OCS source, so startup and shutdown emissions will not be significant from them. It is anticipated that there will be oxidation catalysts on some of the other engines. These catalysts, which are similar to those on automobiles in the United States, warm up in a matter of minutes, so there should be no significant time when these oxidizing control devices are not working. For the *Kulluk* and its fleet, there should be no significant differences in emissions due to startup or shutdown of the sources while the *Kulluk* is an OCS source.

2.6 Emissions from the Associated Fleet

As noted above, even though associated fleet vessels are not part of the OCS source, emissions from vessels servicing or associated with an OCS source must be included in the "potential to emit" for that source while enroute to or from the source when within 25 miles of the source. The potential emissions from the *Kulluk* OCS source and associated vessels when within 25 miles of the *Kulluk*, therefore are included the ambient impacts analysis and the "potential to emit" calculations. The associated fleet is to consist of one primary ice management vessel, one secondary ice management vessel, which also serves as the anchor handler, one OSR vessel (which will carry four small work boats on deck), a possible quartering vessel, and a resupply vessel or vessels. There may be additional associated vessels, such as a tanker or barge or resupply vessel, but these vessels will remain outside a 25-mile radius region from the *Kulluk*, so are not included in the source potential to emit, and because of distance will not contribute to impacts near the *Kulluk*. Restrictions on use of the fleet within the 25-mile radius, which represent reasonable maximum use for drilling purposes, are taken in the form of requested limits, listed in Table 2-5, with potential emission rate limits by source group included in Tables 2-1, 2-2, and 2-3.

2.6.1 Ice Management Vessels

The *Kulluk's* associated fleet is to include a primary ice management vessel and a secondary vessel. The secondary ice management vessel will have the combined duties of light ice management and *Kulluk* anchor handling. Ice management involves deflecting large ice floes that could impact the *Kulluk* and keeping them flowing around the *Kulluk* while it is drilling. Handling of the *Kulluk* anchors involves connecting 12 stabilization anchors to the *Kulluk*, extending the cables out to the anchoring location, and then placing these anchors on the sea floor. It also performs the reverse process. The frequency and intensity of ice conditions is unpredictable and could range from no ice to ice sufficiently dense that the ice management vessels have insufficient capacity to push it out of the way. In this extreme case, the *Kulluk* would need to disconnect from its anchors and move off-site. The 2003–2005 statistics on ice at the Sivulliq drill site in the Beaufort Sea show 15 percent frequency of ice at the drill site that would need to be managed and a 23 percent frequency of ice not at the drill site, but within 30 miles of the drill site. This statistic was included and further explained in the *Discoverer* air permit applications previously submitted to EPA Region 10 ("Outer Continental Shelf Pre-Construction Air Permit Application Revised, *Frontier Discoverer* Chukchi Sea Exploration Drilling Program," February 23, 2009, and "Outer Continental Shelf Pre-Construction Air Permit Application, *Frontier Discoverer* Beaufort Sea Exploration Drilling Program," January 2010). A reasonable maximum probability of needing the ice management vessels is considered the sum of these two, which is 38 percent of the drill season.

When ice is present, the management vessels would be somewhere near or up-floe of the *Kulluk* managing the ice. At most other times these two vessels would be beyond the 25-mile radius from the *Kulluk*. For emission estimation purposes the ice management fleet is assumed to be operating at maximum (nameplate rates) rate for 38 percent of the 120-day OCS period. For modeling purposes, the ice management vessels are assumed to be operating at maximum emission rate whenever the meteorology indicates that ice is present and assumed to be beyond the 25-mile radius when the data indicates open water.

Emission units on each ice management vessel include the propulsion engines and engine-generator sets (generators), heaters, an incinerator, and some seldom-used engines, such as lifeboat propulsion engines and an emergency generator. Depending on the vessel, it can be driven either by direct drive from the diesel propulsion engines or by electric motor from the generators, which in turn are driven by diesel. Thus, there can be a mixture of propulsion directly from propulsion engines or by way of generators. Both engine types are large (well over 1,000 hp) and usually of the same vintage and therefore have similar emission factors. Thus, the generation and propulsion engines are grouped for emission estimation purposes. Although the seldom-used engines will have a variety of emission factors, their emissions are small relative to the propulsion and generation source group. Therefore, this application uses emission factors characteristic of small, higher emitting engines (AP-42, Table 3.3-1, small diesel engine emission factors). In sum, each of the two ice management vessels has four source groups: (1) propulsion and generation, (2) heaters, (3) incinerator, and (4) seldom-used engines. The estimated maximum emissions, which are to be taken as ORLs, are shown on Tables 2-1, 2-2, and 2-3. The propulsion engines and generators will have tailpipe emission controls of oxidation catalyst and SCR to limit the emissions of NOx, PM, CO, and VOCs, with the same control level assumptions as are made for the *Kulluk*.

Maximum emissions from each source group (except the incinerators) on the ice management vessels are estimated using Shell's estimation of the maximum fuel to be consumed per day for each group multiplied by the emission factors in the form of mass of emissions per unit fuel consumed. For the propulsion and generation source group and heaters source group, the maximum fuel consumption assumes engines running at nameplate power level, although normal maximum operating level for propulsion engines is about 85 percent of nameplate rating. For the seldom-used engines source group, Shell estimates the maximum fuel consumption from the frequency and time interval of use of these engines, which is less than one percent of the time. These emissions are extremely small and from multiple small engines being exercised for short periods of time that are unrelated in time to the drilling operation. Without any definition of the times of operation, their emissions will be modeled as averaged over a weekly compliance demonstration period. For the incinerators, maximum daily emissions are the nameplate incineration rate for 24 hours.

2.6.2 OSR Vessel and Quartering Vessels

The OSR vessel will be stationed near the *Kulluk* in preparation for the unlikely event of an oil discharge from the *Kulluk* to the water. There is also likely to be a quartering vessel for the OSR personnel. These vessels will remain in the vicinity of the *Kulluk*, and when practicable, anchored. The OSR vessel moves as may be needed to avoid ice floes, adverse sea conditions, or to assist other vessels in unspecified ways, such as in refueling. The OSR vessel is expected to carry three to four small work boats. These boats are stored on the OSR vessel and are placed in the water to conduct spill response training drills, to move personnel and equipment, and to standby during refueling operations. The OSR fleet will have on-water drills at a maximum frequency of once per day, and up to eight hours for each exercise. The exercise will normally consist of two work boats towing an open apex boom and a third moving equipment.

Emissions from the OSR and quartering vessel are divided into the source groups of (1) the large vessel propulsion and generation on the OSR and quartering vessels, (2) seldom-used engines on the OSR and quartering vessel, and (3) the work boat propulsion and generation engines. Fuel consumption for each is estimated from the maximum level of activity and engine sizes expected for each source group, and maximum vessel sizes. Emissions are estimated using emission factors available either from stack tests or manufacturer's data. The maximum expected daily emissions are proposed as ORLs, which are shown on Tables 2-1 through 2-3.

An additional vessel associated with the OSR fleet will include a tanker and possibly additional vessels that will reside beyond the 25-mile radius of the *Kulluk*. The purpose of these vessels is to provide recovery and storage capacity for oil/water in the unlikely event of a spill. Because of this distance of separation, these vessel emissions are not counted with the associated fleet potential emissions and their emissions impacts would be negligible near the drilling location. So, its emissions are not included in this analysis.

2.6.3 Resupply Vessels – Transport and DP Transfers

Although the *Kulluk* will be provisioned at the start of the drilling season, there may be re-provisioning and refueling needs, and the possible need to remove waste materials, while it is an

OCS source. Different vessels could be used depending on availability and capability. The re-provisioning and refueling will be by DP, where the resupply vessel will hold itself in position a short distance (about 50 feet) from the *Kulluk* hull, without attaching to it, to the resupply vessel stern hull, using its propulsion systems. Materials will be loaded on and off using one of the *Kulluk* cranes. If waste materials such as drill cuttings are to be transported away from the *Kulluk*, they would be loaded onto the re-supply vessel operating in DP mode or onto a barge that would be moored next to the *Kulluk*. While attached, that barge would become part of the OCS source, but would have no emission sources on it. The barge would be brought to and removed from the *Kulluk* using a tugboat that would not attach to the *Kulluk*. In this situation the tug would be considered a resupply vessel.

For emission estimation purposes, the resupply vessel is considered to transport supplies from beyond the 25-mile radius of the *Kulluk* to the *Kulluk*, at which point it shifts to DP mode for transfer of supplies or fuel. It could be in DP mode for a maximum of 24 hours, after which it shifts back to transport mode and leaves the 25-mile radius area. If the resupply vessel is a tug and barge, the tug and barge would come into the area and the barge would connect to the *Kulluk*, taking much less than 24 hours, and then exit the 25-mile radius. Once the barge was loaded or unloaded, the tug would come back, connect to the barge, and transport it away from the *Kulluk*. For emission estimation purposes, there will be a maximum of 24 resupply (including refueling and waste removal) round trips over the 120-day season (and while *Kulluk* is an OCS source). Emissions are calculated assuming use of the largest re-supply vessel Shell is expected to contract.

The two activity modes for the resupply vessel, transport to and from the *Kulluk*, and material transfer in DP mode at the *Kulluk* are mutually exclusive. The first takes about four hours each way and consumes less than half of the fuel consumed in DP mode, which can last a maximum of 24 hours. For maximum daily emission estimates, only the DP mode is considered because it is the larger of the two. DP emissions are estimated with engines operating at a level sufficiently high to control the vessel in higher sea roughness and yet well below engine capacity because there must be considerable reserve to allow for short-term emergencies (including breaking away from DP). This maximum emission rate for the 24-hour period is estimated from a 24-hour DP fuel allotment and these 24-hour emissions are also representative of the shorter-term maximum emissions since the decision to transfer supplies in DP mode is made based on the power required to maintain a position given the roughness of the seas. Sea roughness is driven by synoptic-scale weather patterns, which change over periods of time greater than 24 hours so the assumption of continuous levels of sea roughness over 24 hours is a reasonable one. For annual emissions, both DP and transit emissions are summed over the ORL limit of 24 trips per season.

2.7 Greenhouse Gas Emissions

The greenhouse gas emissions of Carbon Dioxide (CO_2), Methane (CH_4), and Nitrous Oxide (N_2O) are estimated on Page 14 of Attachment A from the potential annual fuel estimate. Carbon Dioxide equivalent (CO_2e) potential is 68,000 tons per year, which is well below the major source threshold of 100,000 tons per year. Thus this source is exempt from the GHG permitting regulations.

2.8 Alternate Operating Scenario – Electrification of some Emission Units

There is some probability that engines such as those on the cranes, HPUs and MLC compressors will be electrified and powered by newer and larger primary generators. If this were to occur, Shell requests that the fuel allotted to any eliminated engines be transferred to the allotment of the primary generators. Shell would provide notification to EPA if this were to occur. Since the primary generators are better controlled and the emission factors (pound per gallon) for the primary generators are lower than for these other engines, this alternate operating scenario would have lower emissions than the base operating scenario. Thus, under this alternate operating scenario, both the impact standards and emission limits would continue to be met.

2.9 Other vessels

There may be scientific study vessels in the Beaufort Sea operating concurrently with the *Kulluk*, as described in approved OCS Exploration Plans (EPs). Their purposes, sizes, emissions, and locations are unknown at this time, and since they will not be directly associated with the drilling program, they are not addressed herein.

SECTION 3

COMPLIANCE WITH THE AMBIENT AIR QUALITY STANDARDS

This section describes the applicable ambient air quality standards (Section 3.1), the modeling methodologies used to determine potential air quality impacts (Sections 3.2 through 3.11), and the results of the impact analyses from Shell's proposed OCS *Kulluk* exploratory drilling operations in the Beaufort Sea (Section 3.12). As summarized in Section 3.12, the maximum modeled impacts of the *Kulluk* and associated fleet show that Shell's proposed *Kulluk* Beaufort Sea exploratory drilling program will comply with the NAAQS/AAAQS.

3.1 Ambient Air Quality Standards

As a minor source and for the leases in the Beaufort Sea, the impact components of the federal and Alaska regulations include requirements to address the NAAQS and the additional AAAQS for ambient NH_3 and RSCs. The NAAQS and AAAQS applicable to Shell's proposed OCS *Kulluk* exploratory drilling operations in the Beaufort Sea are provided in Table 3-1.

3.2 Emissions Based on Realistic Source Exclusivity for Purposes of Modeling

As described in Section 2.4, there are physical restrictions limiting the use of some emission units concurrently with others. For example, there can be no cementing or logging when there is MLC drilling or well drilling. The HPUs are only used for the drilling of the MLC, less than a five-day activity per well. Shell has demonstrated compliance under at least three mutually exclusive operating scenarios and for periods of time during the drilling season that are realistic. Shell also has demonstrated compliance with the ancillary vessels at any location, so permits should not have spatial use restrictions.

Table 3-1: National and Alaska Ambient Air Quality Standards

	Averaging Time	NAAQS/AAAQS [1] ($\mu g/m^3$)
Nitrogen Dioxide (NO_2)	1-hour [2]	188 (100 ppb)
	Annual	100 (53 ppb)
$PM_{2.5}$	24-hour [3]	35
	Annual	15
PM_{10}	24-hour [4]	150
SO_2	1-hour [5]	196 (75 ppb)
	3-hour [6]	1,300 (0.5 ppm)
	24-hour [6]	365 (0.14 ppm)
	Annual	80 (0.03 ppm)
CO	1-hour [6]	40,000 (35 ppm)
	8-hour [6]	10,000 (9 ppm)
NH_3	8-hour [6]	2,100
RSCs	30-minutes [6]	50

[1] National Ambient Air Quality Standards and Alaska Ambient Air Quality Standards.

[2] To attain this standard, the 3-year average of the 98th percentile of the daily maximum 1-hour average must not exceed 100 part per billion (ppb).

[3] To attain this standard, the 3-year average of the 98th percentile of 24-hour concentrations must not exceed 35 $\mu g/m^3$.

[4] Not to be exceeded more than once per year on average over 3 years.

[5] To attain this standard, the 3-year average of the 99th percentile of the daily maximum 1-hour average must not exceed 75 ppb.

[6] Not to be exceeded more than once per year.

3.2.1 Emission Sequencing to Replicate Mutually Exclusive Activities

Shell has accounted for the mutually exclusive activities in modeling of the maximum impacts in the following way. Assuming four wells per season are to be drilled, the emissions are sequenced as four wells, each with 5 days of MLC drilling, followed by 12 days of drilling of the well, followed by 13 days of logging, cementing, and casing, which equals a total of 30 days per well and 120 days of activity for four wells and as an OCS source total per sea. Since MLC drilling activity has higher impacts than either of the two other activities, its duration is limited to 20 days by ORL. If MLCs take place only 10 days, drilling of the well would be allowed for an extra 10 days, for a total of 22 days for that well. Impacts during these additional 10 days would be lower because drilling emissions are the same as MLC except that the air compressors and MLC HPU units would be turned off. Likewise, if MLCs and drilling of the well combined are less than 68 days, then there can be logging, cementing, and casing for more than 52 days per sea-season.

3.2.2 Proposed Emission Sequencing to Replicate Intermittent Activities

Resupply and waste removal events are limited by ORL to a maximum of 24 trips per season. To replicate this intermittent activity for modeling purposes, the resupply vessel emissions in DP mode are turned on for 24 hours every fifth day. The emergency generator on the *Kulluk* is exercised for two hours every 30 days. To replicate this for modeling purposes, the model assumes that emissions of this generator are turned on to capacity for two hours, applied to the hours of noon to 2 p.m., every 30 days. When the emergency generator is not turned on to capacity for two hours, the emissions from seldom-used sources (several small engines, possibly including the emergency generator at low loads) will occur at undefined times and are evenly spread over the 30-day period and modeled from the emergency generator stack.

The ice management fleet is to be managing ice only when there is ice present near the drill site. At other times, it is beyond the 25-mile radius of the *Kulluk*. For modeling, ice management is included when there is ice present near the site as defined by the dispersion meteorological data set (which is also when AERMET is used to process the meteorological data) and will be out of the 25-mile radius when there is no ice (when COARE is used to process the meteorological data). Attachment B provides more information on open-water and ice conditions in the Beaufort Sea.

The *Kulluk* incinerator is limited by ORL to operation within the 12-hour period between 8 a.m. and 8 p.m. The incinerator emissions are turned on and off accordingly in the impact analysis. A table summarizing the operating duration and frequency for the *Kulluk* and associated fleet sources is provided in Table 3-2. In addition, Table 3-3 provides a breakdown of one 30-day well drilling sequence for the impact analysis.

In order to eliminate possible bias in the meteorology used for the impact analysis, hypothetical 120-day emission sequences are modeled with early season meteorology (likely better dispersion), July 1 through October 28, and late-season meteorology (likely worse dispersion and stable ice conditions), August 3 through November 30, and the higher impacts of the two are taken as representative. The purpose of this is to find the sequence with highest coupled impacts plus background to be compared with the 98th percentile standards for 1-hour NO_2 and 24-hour $PM_{2.5}$ (see Sections 3.9 and 3.10).

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Table 3-2: Summary of Source Operating Duration and Frequency

Sources		Source Operate During? MLC	Drilling	Cementing/ Logging	Operating Duration (hr/day)*	Operating Frequency
Kulluk						
Generation	MAINENGS	Yes	Yes	Yes	24	Every day of listed activity
MLC HPUs	MLCHPU_A, _B	Yes	No	No	24	Every day of listed activity
Air Compressors	AIRCMP_A, _B	Yes	No	No	24	Every day of listed activity
Cranes	CRANE_A, _B, _C	Yes	Yes	Yes	24	Every day
Heaters and Boilers	HEATBOIL	Yes	Yes	Yes	24	Every day
Incinerator	INCIN_K	Yes	Yes	Yes	12 (8am - 8pm)	Every day
Seldom-Used Units (typical operations)	SELDOML	Yes	Yes	Yes	24	Every day
Seldom-Used Units (emer. gen. exercising)	SELDOMH	Yes	No	No	2 (12pm - 2pm)	Every 30 days
Associated Fleet						
Resupply Ship	RESUP_DP	Yes	Yes	Yes	24	Every 5 days
Ice Management	ICEMGMT	Yes	Yes	Yes	24	On days when ice is present
OSR Ship	OSR_MAIN	Yes	Yes	Yes	24	Every day
Quarterting Ship	OSR_QTR	Yes	Yes	Yes	24	Every day
OSR Work Boats	OSR_WORK	Yes	Yes	Yes	24	Every day

* When the source is operating.

Table 3-3: Breakdown of One 30-Day Well Drilling Sequence for the Impact Analysis

	Operations (hours/day)																													
	MLC (5 days)					*Drilling (12 days)*												*Cementing and Logging (13 days)*												
Source	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Kulluk																														
Generation	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24
MLC HPUs	24	24	24	24	24	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
Air Compressors	24	24	24	24	24	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
Cranes	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24
Heaters and Boilers	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24
Incinerator [1]	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12
Seldom-Used Units (typical operations)	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24
Seldom-Used Units (emer. gen. exercising) [2]	---	---	---	---	2	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
Associated Fleet																														
Resupply Ship [3]	---	---	---	---	24	---	---	---	---	24	---	---	---	---	24	---	---	---	---	24	---	---	---	---	24	---	---	---	---	24
Ice Management [4]	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24
OSR Ship, OSR Work Boats, Quarterting Ship	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24

[1] Incinerator operates from 8 a.m. to 8 p.m. every day.

[2] Emergency generator is exercised 2 hours every 30 days (12 p.m. to 2 p.m. assumed).

[3] Resupply ship has 24 visits to the *Kulluk* every 120 days (i.e., one visit every 5 days).

[4] Ice management only occurs when ice is present; no ice management during open water conditions.

3.3 Physical Characterization of the Emission Units

3.3.1 Kulluk

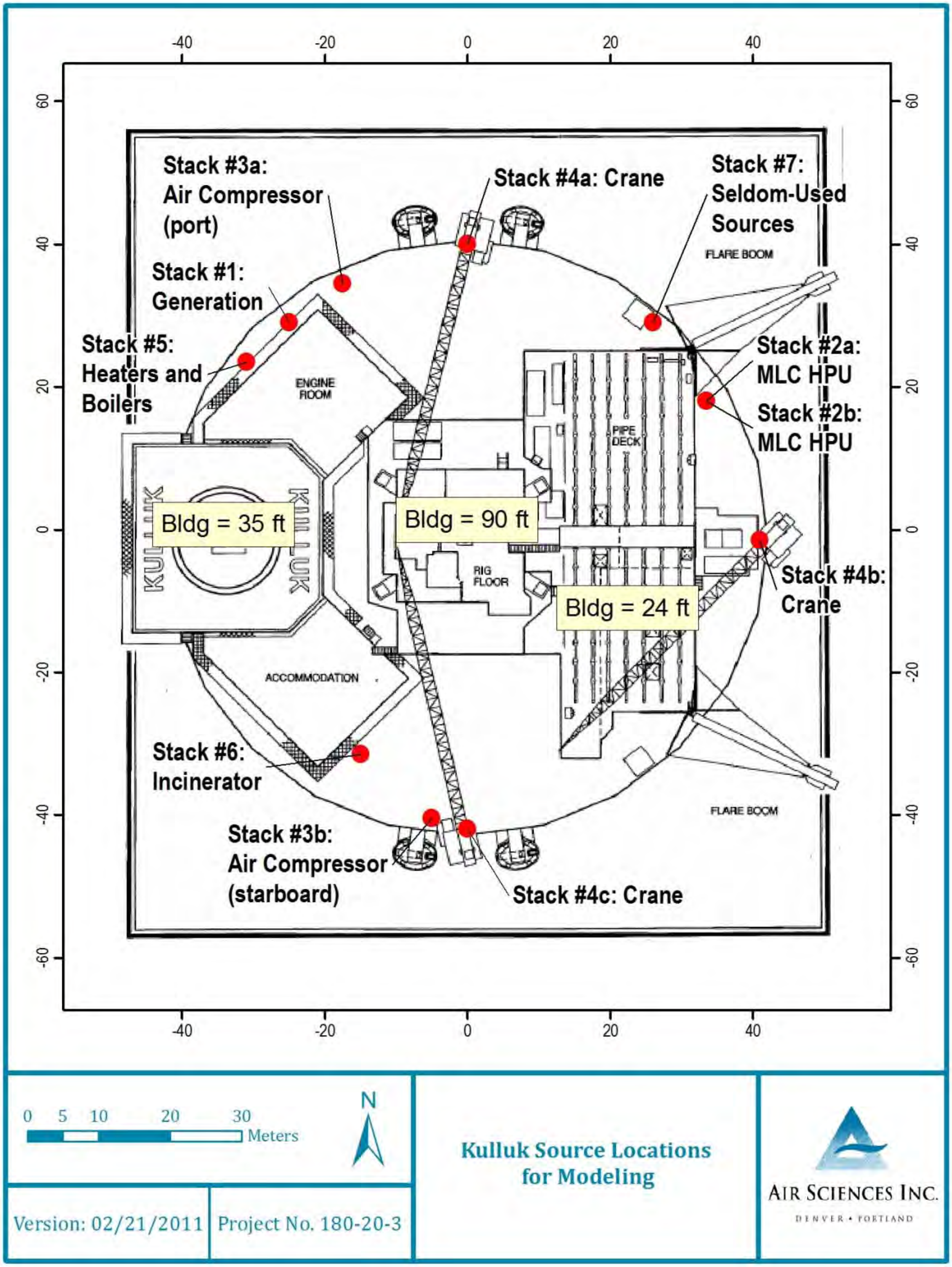
A plan view of the *Kulluk* preliminary source unit configuration is provided in Figure 3-1.

Per EPA's Screening Procedures for Estimating the Air Quality Impact of Stationary Sources, Revised (EPA-454/R-92-019, October 1992) document: sources that emit the same pollutant from several stacks with similar parameters that are within about 100 meters of each other may be analyzed by treating all of the emissions as coming from a single representative stack. Several sources on the *Kulluk* are located next to each other, and merging the stacks for modeling purposes is appropriate because of similarities in source size and location. For these, single-source stack parameters with combined emissions are used by Shell (e.g., three generation stacks are modeled as a single stack). For other sources (e.g., three cranes), Shell has chosen not to pursue source co-locations and to explicitly model each individual stack on the *Kulluk*.

Given the configuration of the stacks and structures on the *Kulluk*, plumes may be down-washed and pulled into the structures' wake region. For the analysis, the structure downwash parameters used in AERMOD are calculated using the Building Profile Input Program (BPIP) (Version 04274). The building height and location information used in the BPIP analysis are also indicated on Figure 3-1. Attachment E, Page 3 also contains the specific building coordinates used in the BPIP analysis.

Although each well is expected to take no more than 30 days to complete, at which time the *Kulluk* will move to another location, the impact modeling is performed under the assumption that the *Kulluk* remains at a single location for 120 days. Thus the impact modeling includes four times as much emissions and days of impact than should actually occur at any one location. Furthermore, on these days, the sources are emitting at their maximum (their PTE) which in practice never happens continuously. Thus the impact modeling for the *Kulluk* will produce impacts above that which would be expected from actual *Kulluk* drilling activities.

Figure 3-1: Layout of Emission Units on the Kulluk



3.3.2 Emissions as a Function of Load

There are occasional circumstances when impacts from a source are higher at partial load than at full load. A loads analysis was performed to compare load vs. impact for the hourly NOx impact and 24-hour $PM_{2.5}$ impact from the *Kulluk* generators at two loads, the maximum of which is 100 percent of nameplate rating, and the operationally desirable minimum operating level of half (50 percent) of nameplate rating. Although these engines do not cause the largest local impacts, they are representative of different models of diesels and therefore should be representative of the smaller engines also. These are the engines that have the most complete emissions at partial load data available. Incinerator emissions at various loads are not available in the literature or from the manufacturer. Its anticipated use pattern is to receive occasional batches and to supply heat at design heat rate for short periods of time; so it would emit at capacity rate but for short periods of time.

As mentioned above, the *Kulluk* generator engines were modeled at two loads, 50 and 100 percent load. Each load has a separate emission factor and set of stack parameters, provided in Attachment E, Page 1 with references. From this table it is apparent that even though the engines may operate at low loads, it is the emissions and stack parameters of maximum load that causes the highest emissions and impacts. Therefore the impact analysis results summarized in Section 3.12 are based on engines operating at maximum load. Note that the ice management and anchor handler ships are also considered in the impact analysis at maximum load. Based on previous evaluations of these types sources (*Discoverer* PSD permit applications, revised September 2009) the maximum impacts occur at the maximum loads levels.

3.3.3 Associated Fleet

With respect to the modeling of impacts from the vessels associated with the *Kulluk*, the ice management/anchor handling vessels, the resupply/waste removal ship, and the OSR/quartering vessels are all considered to be generic vessels. Emissions from all three are estimated as described in Section 2.4 and their impacts are included in the analyses.

The locations of these vessels are on an as-needed basis and changing with winds, environmental conditions, supply needs, training needs, and so on. For ice management purposes, the vessels will generally be within a 5 kilometers (km) radius of the *Kulluk*, but when there is no ice present, which is most of the time, they will be more than 25 miles away. The ice floes are primarily driven by the wind, but sea current also affects the direction of the ice floe, so during ice management the vessels will be generally upwind, but not necessarily directly upwind.

Location of the ice management vessels and associated emissions for modeling purposes during ice management is evaluated based on earlier experience with the *Kulluk. (Full Scale Experience with Kulluk Stationkeeping Operations in Pack Ice [With Reference to Grand Banks Developments] submitted to The National Research Council of Canada [on behalf of PERD Sub-Task 5.3 Oil & Gas]*

PERD/CHC Report 25-44, B. Wright & Associates Ltd., July 2000, Section 5.5.) This report provides a thorough explanation of ice management practices, based on experience with the *Kulluk* drilling in the 1980s. Depending on the type of ice, speed, and direction of ice floe, there are different patterns that could be used to fragment the ice so that it can flow around the *Kulluk*. For ice that is not thick, there is intermittent use of the icebreakers, and for fragmenting the ice the vessels would travel at relatively high speed, up to 10 knots (kts) (the High Speed Approach) taking about 30 minutes to fragment a typical 1 km x 5 km area up-floe of the *Kulluk*. Then they would stand idle for a period of time. When there is minimal ice motion, the vessels would fragment the ice in the area around the *Kulluk* and then stand idle for the next fragmentation episode. For thicker and moving ice, which is common in the Beaufort, the "Picket Boat Approach" would generally be used. With the Picket Boat Approach the vessels are continually fragmenting at higher power so this approach to ice fragmenting is assumed for purposes of estimating maximum emissions and for defining location of the vessels during periods of maximum emissions for impact modeling purposes.

With the Picket Boat Approach, the up-flow distance to the nearer ice management vessel is based on the need to be located six hours up-flow, which is the time it would take for the ice at that location to reach the *Kulluk*. At an average floe speed of 0.15 meter per second (m/s), the up-flow distance of the nearer vessel would be 3.24 km. The primary vessel would be farther up-flow. No distance is provided for this primary vessel in the study, so it is estimated to be 5 km based on separation distance between vessels for safety purposes. So, for impact modeling purposes, the vessels could range anywhere from the *Kulluk* out to 5 km in ice management activities that consume the higher level of power (assumed to be maximum propulsion power). The "picket" work would be with the secondary vessel that could come near the *Kulluk* to clear around the hull. Thus, the ice management vessel emissions are defined as occurring uniformly throughout a pie-shaped area within a 5 km radius from the *Kulluk*. The width of this area is estimated from Figure 5-4 of the study, and the text to be approximately 40 degrees. The ice management vessels average between 6 and 9 kts (7 to 10 miles per hour (mph)) during this mode of ice management activity, so in one hour, each would travel 7 to 10 miles in this 5-km-radius area. This distance represents thorough spreading of emissions across the source pie-shaped area.

The ice management vessels are characterized as area sources, rather than volume sources because the Plume Volume Molar Ratio Method (PVMRM) code in the regulatory version of AERMOD has known coding errors for volume sources, and because a recent EPA beta version of AERMOD has a limitation regarding the changing of source location on an hourly basis. The current regulatory version of AERMOD has a known error in the PVMRM code which incorrectly overestimates the NO_2 chemistry of point sources when volumes sources are also included in the model runs.

EPA has provided Shell a beta version of the AERMOD code which addresses the PVMRM volume source errors. For selected hours, Shell has verified that the current regulatory version of AERMOD and the beta version of AERMOD produce similar impacts for area sources (i.e., there are no PVMRM code errors in the area source routine of the regulatory version of AERMOD). However, the AERMOD beta code which incorporates code corrections for volume sources with the PVMRM algorithms for evaluation of NO_2 impacts, currently does not allow the changing of source locations hour by hour as is integral to the characterization of the *Kulluk* associated fleet. The largest sources for the *Kulluk* project are the ice management vessels which relocate hourly as a function of wind direction. Thus, an area source configuration of the ice management vessels for the *Kulluk* impact analysis is appropriate both a source characterization standpoint as described above and from a practical standpoint regarding EPA's AERMOD tools which are available for modeling the Shell project.

The anchor handler is also used for handling anchors and bow washing, an activity that requires the vessel to back up to within tens of meters of the *Kulluk* and turn its propellers to dislodge possible patches of ice frozen to the *Kulluk's* hull. This activity, and that of anchor handling, are near the *Kulluk*, but are at low power, and therefore, low emission levels. The bow washing activity will occur within the pie-shaped areas described above for modeling the ice management vessel emissions.

Unlike the ice management vessels that will be moving continuously when managing ice and within 5 km of the *Kulluk*, the OSR and quartering vessels are expected to be located to the side or downwind of the *Kulluk*, generally in a location where the ice will have been diverted to flow past the *Kulluk* in the range of 1 to 5 km from the *Kulluk*. For modeling purposes, the emissions from the OSR and quartering vessels are located adjacent to the hull of the *Kulluk* and are spread throughout a 2 km by 2 km area. This source characterization is conservative since the OSR sources are continuously located much closer to the *Kulluk* than what would occur in reality. This design also takes into account scenarios where ships would need to approach the *Kulluk* for purposes such as refueling and transfer of personnel.

Since the emissions from resupply DP mode are higher than in transit, and since emissions from transit are spread over a large area, the re-supply/waste removal vessel is modeled in the DP mode. During DP mode, the resupply/waste removal vessel is stationary, and defined as a point source with a separation distance of 50 feet from *Kulluk* hull (near a *Kulluk* crane) to re-supply vessel stern.

To determine the hourly plume heights and sigma Z values as a function of hourly meteorological conditions for the ice management/anchor handler fleet, AERMOD is used in a two-step process:

1. A line of receptors at several distances downwind out to 5 km (i.e., the extent of the ice management areapoly source) from Shell's expected ice management vessel with the lowest stack height are generated and AERMOD is run on an hour-by-hour basis to generate AERMOD's debug file, and
2. The results from #1 are used to determine the receptor with the highest concentration for the given hour for the ice management fleet (in AERMOD's debug file[1]). Then, the plume height and sigma Z values at this maximum impact receptor are used as the initial plume height and initial sigma Z values of the elevated area sources in AERMOD. This approach couples the worst-case hourly ice management impacts with the *Kulluk* impacts in the full modeling analysis.

These emission heights and area source heights are calculated on an hour-by-hour basis for use in the impact assessment. The ice management/anchor handler potential emissions are then spread throughout this elevated, pie-shaped area source.

Note that the Vladimir Ignatjuk is selected for the ice management vessel in #1 since it is the ice management/anchor handler ship with the lowest stack height and it was the ice management ship resulting in the lowest plume heights of any candidate ship in previous ice management plume height evaluations (*Discoverer* PSD permit applications, revised September 2009). The Vladimir Ignatjuk ship provides a conservative estimate of plume heights for the generic ice management ships to be permitted as part of the *Kulluk* exploratory drilling operations in the Beaufort Sea.

A similar approach was used to determine the hourly plume heights and sigma Z values for the area sources used to characterize the main OSR ship (the OSR work boats), and the quartering ship. In the case of the OSR ships, the evaluation in #1 above was based on impacts downwind to 2 km (i.e., the extent of the OSR areapoly sources). Information on the ships used in this analysis are provided in Attachment F.

Table 3-4 provides a listing of the source locations and source release parameters used in the impact analysis. Figure 3-2 provides a close-up overview of the *Kulluk* and associated fleet used in the impact analysis. Figure 3-3 is a graphic showing the entire modeled configuration of ice management/anchor handler and OSR/quartering area sources (areapoly sources in AERMOD). Attachment A contains the emissions inventory for the *Kulluk* and associated fleet, including a source-by-source summary of emission rates used in the impact analyses.

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[1] The resulting MODEL.DBG output file was used to determine the area source plume height and sigma Z values in several steps as recommended by the USEPA [Thurman, James A., USEPA , Communications with M. Wright, Air Sciences, Inc.] November 30, 2010, December 1, 2010 and December 6, 2010.

Table 3-4: Source Locations and Source Release Parameters Used in Impact Analysis

Point Source Description	Model Src. ID	Source Coordinates X (m)	Source Coordinates Y (m)	Source Type	Release Height Above Main Deck (m) [1]	Release Height Above Water (m)	Exit Temperature (deg K)	Exit Velocity (m/s)	Stack Diameter (m)
Stack #1: Generation [4]	MAINENGS	-38.2	2.8	POINT	6.40	13.72	606	30.5	0.60
Stack #2a: MLC HPU [5]	MLCHPU_A	11.0	36.4	POINT	3.05	10.36	700	40.0	0.18
Stack #2b: MLC HPU [5]	MLCHPU_B	11.0	36.4	POINT	3.05	10.36	700	40.0	0.18
Stack #3a: Air Compressor (port) [4]	AIRCMP_A	-36.8	12.0	POINT	3.66	10.97	606	30.5	0.60
Stack #3b: Air Compressor (starboard) [4]	AIRCMP_B	25.1	-32.2	POINT	4.69	12.01	606	30.5	0.60
Stack #4a: Crane [5]	CRANE_A	-28.3	28.3	POINT	16.99	24.31	672	20.1	0.25
Stack #4b: Crane [5]	CRANE_B	30.1	27.9	POINT	16.99	24.31	672	20.1	0.25
Stack #4c: Crane [5]	CRANE_C	29.7	-29.7	POINT	16.99	24.31	672	20.1	0.25
Stack #5: Heaters and Boilers [5]	HEATBOIL	-38.5	-5.3	POINT	6.40	13.72	366	16.1	0.15
Stack #6: Incinerator [5]	INCIN_K	11.7	-32.9	POINT	8.81	16.12	623	10.0	0.46
Stack #7a: Seldom-Used Units (typical operations) [6]	SELDOML	-2.1	38.9	POINT	5.76	13.08	700	40.0	0.18
Stack #7b: Seldom-Used Units (emerg. gen. exercising) [6]	SELDOMH	-2.1	38.9	POINT	5.76	13.08	700	40.0	0.18
Stack #8: Resupply Ship [7]	RESUP_DP	87.7	81.5	POINT	---	18.29	650	14.6	0.60

Areapoly Source Description	Model Src. ID	Source Coordinates X (m)	Source Coordinates Y (m)	Source Type	Release Height Above Water (m)	# Nodes	Sigma Z (m)
Areapoly #1: Ice Management/Anchor Handler Ships	ICEMGMT	Varies Hourly [2]		AREAPOLY	Varies Hourly [2]	11	Varies Hourly [2]
Areapoly #2: Main OSR Ship	OSR_MAIN	Varies Hourly [3]		AREAPOLY	Varies Hourly [2]	14	Varies Hourly [3]
Areapoly #3: Quartering Ship	OSR_QTR	Varies Hourly [3]		AREAPOLY	Varies Hourly [2]	14	Varies Hourly [3]
Areapoly #4: OSR Work Boats	OSR_WORK	Varies Hourly [3]		AREAPOLY	Varies Hourly [2]	14	Varies Hourly [3]

1 Above main deck which is 7.3 meters (24 feet) above the water surface
2 Determined from an analysis of the ice management/anchor handler ship with the lowest stack height (Vladimir Ignatjuk).
3 Determined from analysis of OSR fleet's ships; The main OSR ship is the Pt. Oliktok, the quartering ship is the Nanuq, and the OSR work boats.
4 From *Kulluk* 8/2007 stack test (100% load).
5 From *Kulluk* 2007 permit application. Stack heights revised per e-mail from Marshall Borden on 11/22/2010.
6 Assume similar to MLC HPUs.
7 ETI, 2010 M/V Harvey Spirit Main Propulsion Engine Starboard Engineering Testing Stack test report, 9/21/10;
ETI, 2010 M/V Harvey Spirit Main Propulsion Engine Starboard Engineering Testing Stack test report, 9/21/10.

Figure 3-2: Close-up Overview of the Kulluk and Associated Fleet Configuration Used in the Impact Analysis

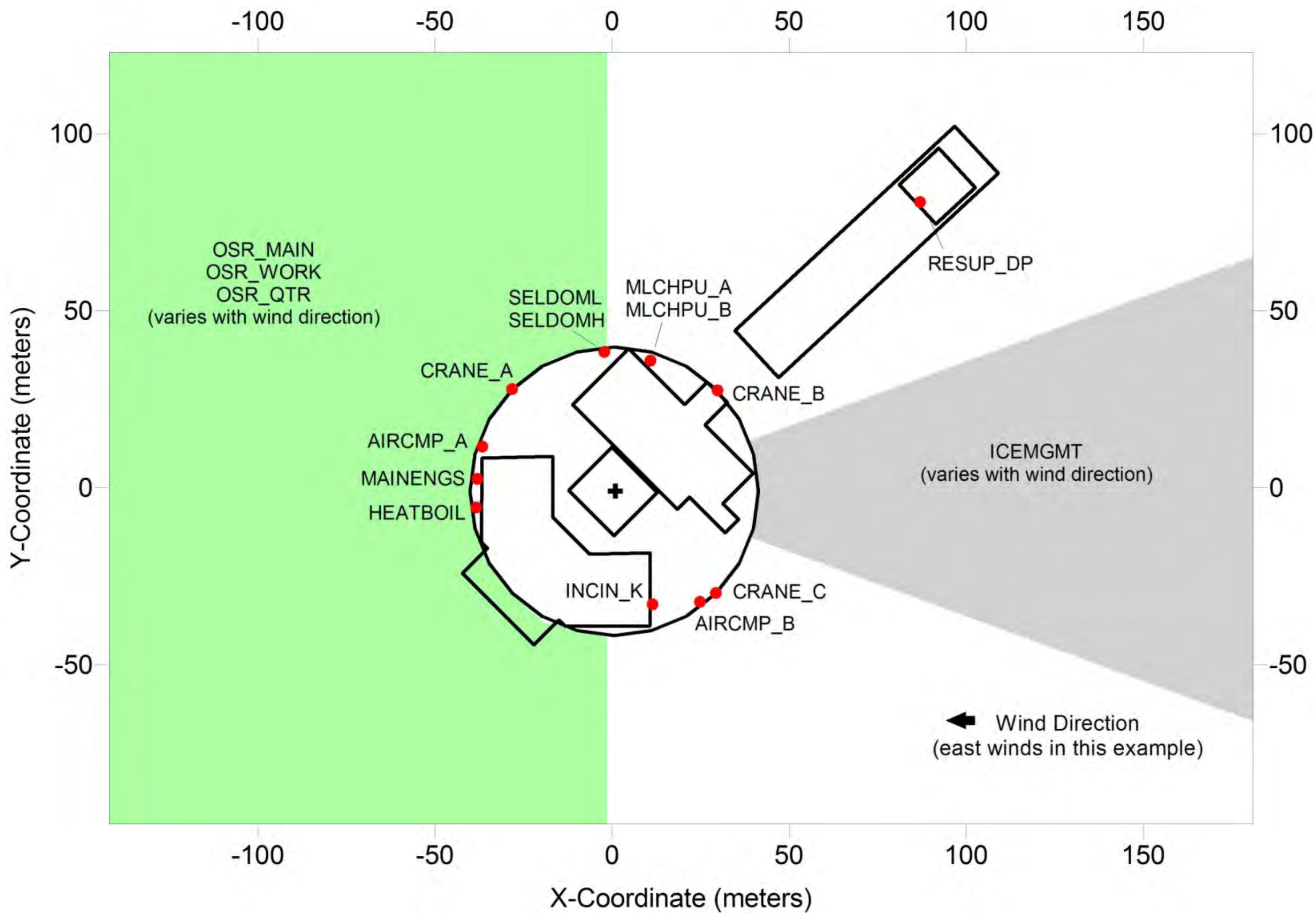
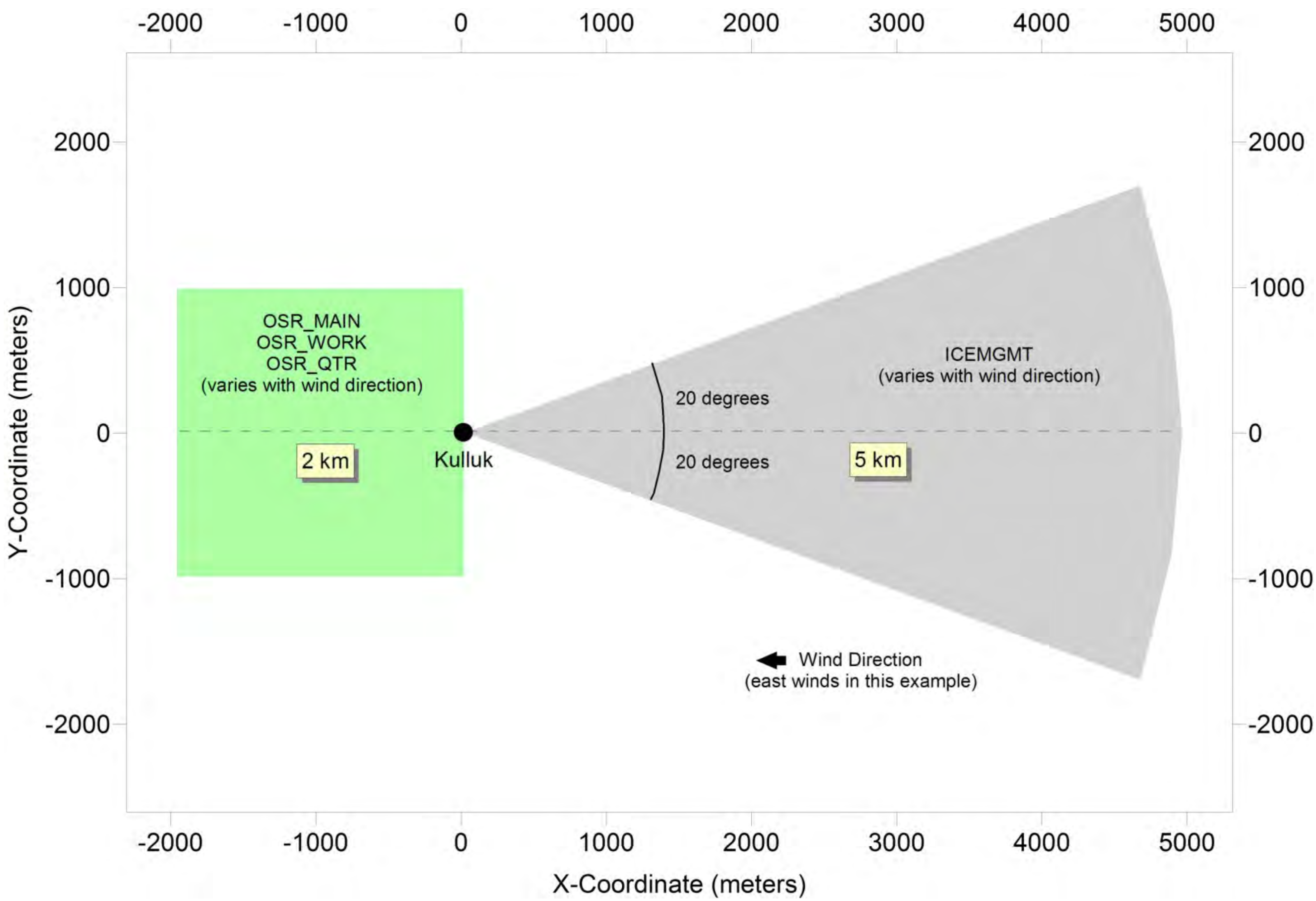


Figure 3-3: Full-Extent Overview of the Kulluk and Associated Fleet Configuration Used in the Impact Analysis



3.3.4 Associated Vessels Stack Heights as a Function of Power Level

With an unspecified and year-to-year changing fleet such as this, and in particular for the re-supply vessels, which will have a relatively high impact during DP mode, the vessel with the highest impact was used in the impact analysis. Normally the largest vessels have the largest impact, because they have the highest propulsion power and therefore highest emissions, even though they also have the highest exhaust stacks. This modeling analysis includes a demonstration that the largest vessels of those anticipated for the re-supply do indeed have the highest impact. The analysis consisted of modeling the impacts of the vessel with highest propulsion power (Harvey Spirit) and the vessel with lowest propulsion power (Arctic Seal) of the range of vessels for re-supply as shown in Table 3-5. Attachment E, Page 2 provides details of an impact comparison between the Harvey Spirit and Arctic Seal for Shell's most constraining ambient standards, 1-hour NO_2 and 24-hour $PM_{2.5}$, and indicates that the Harvey Spirit is the highest impacting resupply vessel during DP mode operations. Therefore the impact analysis results summarized in Section 3.12 are based on the Harvey Spirit as the resupply ship for the *Kulluk*.

Table 3-5: Candidate Re-supply Vessels Stack Heights as a Function of Propulsion Power Level

Vessel	Total Propulsion (hp)	Stack Height (m)
Arctic Seal	1,700	8.6
Harvey Spirit	6,140	18.3
Ocean Titan	5,000	10.1
Harvey Explorer	4,520	18.3

3.4 Model Selection

It is Shell's understanding from verbal discussions at a September 23, 2010 meeting between Shell and EPA that R10 does not object to Shell's use of AERMOD with PVMRM chemistry (for NO_2 modeling) and AERMOD without PVMRM chemistry for all other pollutants (e.g., CO, PM, SO_2) using offshore meteorology (e.g., Reindeer Island) to model its OCS sources.

To apply AERMOD at offshore locations, Shell has utilized an approach to attempt to better simulate open-water conditions (compared to running the conventional AERMET meteorological data processor for AERMOD) by using the Reindeer Island tower and buoy data sets (see Section 3.5) to prepare a meteorological data set suitable for AERMOD. This approach by-passes AERMET during periods when the sea ice has given way to open water and would utilize similarity concepts as described in more detail in Attachments B and C. The alternative approach by-passes the AERMET meteorological preprocessor using the COARE air-sea flux algorithm[2] and overwater meteorological measurements. R10 has encouraged use of AERMOD with an AERMET-by-pass approach to the meteorological data if the approach does not bias toward underestimations. An analysis of this approach is currently being reviewed by EPA.[3]

For this analysis, the most recent version (09292) of AERMOD was used to estimate air quality impacts resulting from sources of emissions at the project. AERMOD is an advanced modeling system that incorporates boundary layer theory, turbulence, and effects of terrain features into air dispersion simulations. It is an EPA-recommended guideline model which is appropriate to determine impacts from Shell operations at offshore locations. AERMOD has several technical benefits that are important when modeling impacts from OCS sources that are not available in Offshore and Coastal Dispersion (OCD) model.

First, AERMOD directly incorporates the Ozone Limiting Method (OLM) and PVMRM chemistry algorithms in the model code while OCD does not. In order to utilize the PVMRM chemistry, a model with PVMRM directly coded into the model is necessary (e.g., PVMRM cannot be utilized as a post-processing routine). AERMOD is the only Guideline model that incorporates PVMRM.

PVMRM has been judged to provide unbiased estimates of the NO_2/NOx ratio based on criteria that are comparable to, or more rigorous than, evaluations performed for other dispersion models that are judged to be refined, implying unbiased performance.[4] In addition, performance evaluations show that the PVMRM can realistically predict the NO_2 fraction at close-in receptors, yet still provide conservative estimates so that the air quality standards can be protected[5]. PVMRM better simulates the Nitric Oxide (NO) to NO_2 conversion chemistry during plume expansion compared to OLM, which uses a simplified approach to the reaction chemistry. In addition, PVMRM is particularly well-suited for the near-field receptor area (also important to Shell OCS modeling), where maximum modeled NOx concentrations are usually predicted.[6]

Second, AERMOD contains routines to handle calms or periods of missing data while OCD does not. OCD output files must be post-processed with routines similar to CALMPRO.

Third, EPA is currently incorporating internal routines in AERMOD to calculate the 98th and 99th percentile concentrations necessary for comparisons with the new 1-hour NO_2 and SO_2 ambient

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[2] Version 3.0 of the COARE algorithm with journal references can be accessed at: ftp://ftp.etl.noaa.gov/user/cfairall/wcrp_wgsf/computer_programs/cor3_0/

[3] ENVIRON 2010b. *Evaluation of the COARE-AERMOD Alternative Modeling Approach, Support for Simulation of Shell Exploratory Drilling Sources In the Beaufort and Chukchi Seas.* ENVIRON, 19020 33rd Avenue W, Suite 310, Lynnwood, WA 98036; Job No. 0322090, December 16, 2010.

[4] MACTEC, 2005. Evaluation of Bias in AERMOD-PVMRM. Final Report, Alaska DEC Contract No. 18-9010-12. MACTEC Federal Programs, Inc., Research Triangle Park, NC.

[5] Hanrahan, P.L., 1999. The Plume Volume Molar Ratio Method for Determining NO_2 / NOx Ratios in Modeling—Part II: Evaluation Studies. *J. Air & Waste Manage. Assoc.*, 49: 1332–1338.

[6] Hanrahan, P.L., 1999. The Plume Volume Molar Ratio Method for Determining NO_2 / NOx Ratios in Modeling—Part I: Methodology. *J. Air & Waste Manage. Assoc.*, 49: 1324–1331.

standards. These and other future refinements to AERMOD will not be available to OCD unless EPA decides to update and support this model.

Fourth, AERMOD incorporates the updated prime downwash algorithms, which have improved upon the older, more simplistic building downwash scheme included in OCD. Building downwash plays an important role for Shell's OCS sources when calculating impacts at near-field receptors. For prior permitting actions of Shell OCS sources, the prime downwash algorithms (in ISC-PRIME) were utilized for this reason. Thus, there is precedent for using PRIME with OCS permitting. For its continued permitting of similar exploration activities, Shell believes that AERMOD is a relevant option for modeling OCS activities given that the Shell OCS leases are for the most part tens of miles offshore, and the highest impacts from Shell's OCS activities will occur at receptors located near the offshore drilling locations.

Fifth, the environmental condition associated with highest emissions is drilling and simultaneous ice management, which occurs with ice floes and not open water. During this condition, the ice management ships are managing the ice, essentially fragmenting it so that it will flow around the drill vessel, but there is negligible open water nearby the drill vessel. AERMOD is more appropriate than OCD in these surface conditions. During open water circumstances, the ice management fleet is over 25 miles away from the drill ship (to avoid being a part of the OCS source). By focusing the impact analysis on this condition, the highest impacts should be more accurately modeled.

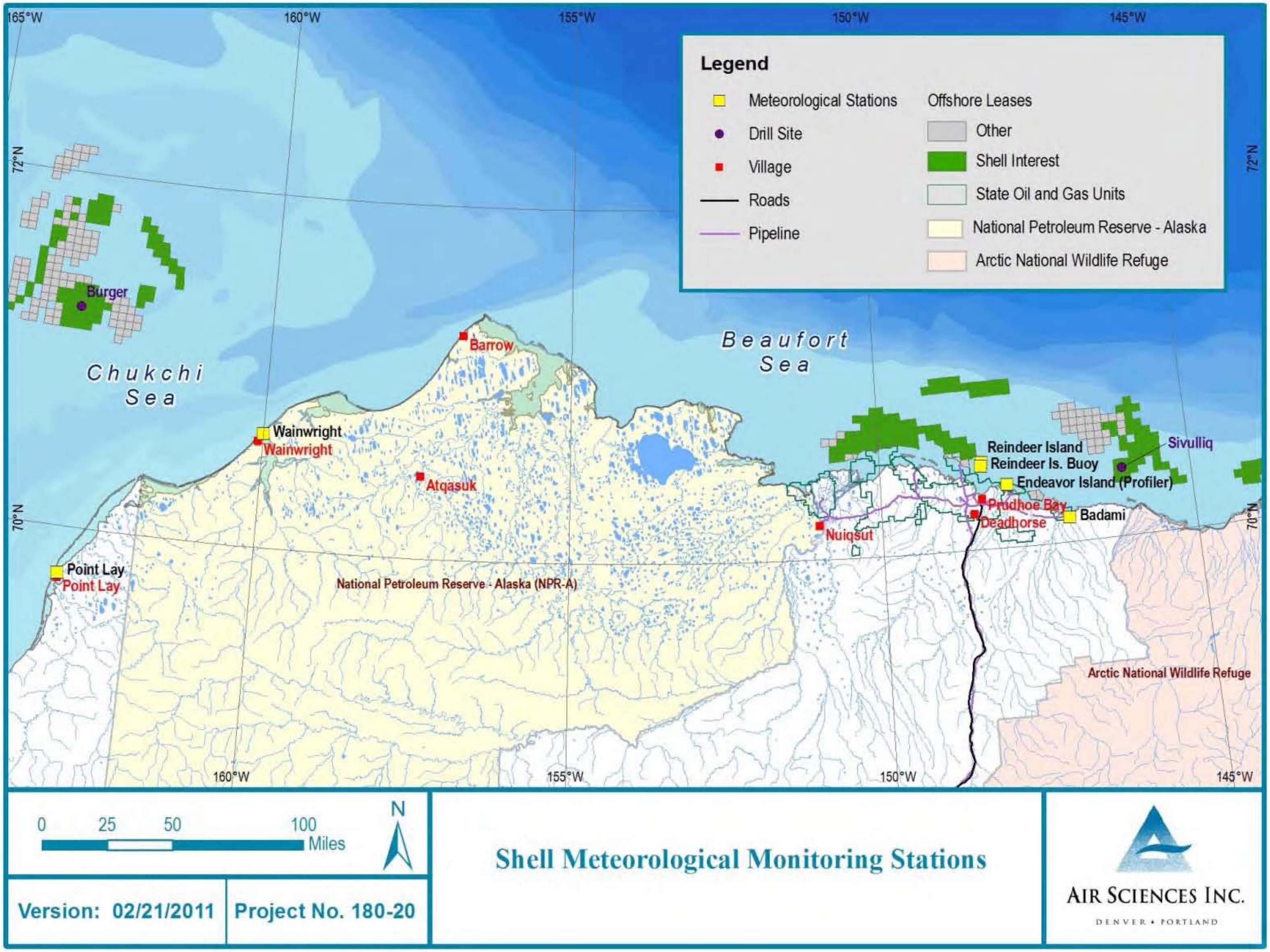
In addition, it is Shell's understanding that EPA Region 4 has previously allowed the use of AERMOD for OCS modeling analyses in the Gulf of Mexico so there is EPA precedence for the use of AERMOD to determine offshore impacts.

3.5 Meteorological Data

3.5.1 Overview of Shell's Meteorological Stations

Shell operates a meteorological collection network in northern Alaska (both the Beaufort and Chukchi Seas and coastal areas) to provide data for modeling applications of both offshore and onshore sources in the North Slope region. Shell's meteorological collection effort focuses on both coastal and offshore locations of the North Slope as shown in Figure 3-4. Surface meteorological observations in this region are or will be collected at Badami (or a possible Barter Island/Kaktovik replacement), Reindeer Island and Endeavor Island, Wainwright (with Conoco Phillips), and Point Lay. A buoy was operated near Reindeer Island during the summers of 2009 and 2010. In 2009 and 2010, offshore data were also collected at a buoy operated by Shell Exploration and Production Company (SEPCO) to support exploration activities in the Beaufort and Chukchi Seas. A Beaufort Sea buoy was located near the Sivulliq prospect and a Chukchi Sea buoy was located near the Burger prospect. A thermal profiler has been installed at Endeavor Island to collect data on the boundary layer structure and mixing heights.

Figure 3-4: Map of Shell Meteorological Monitoring Stations on the North Slope



As of January 2011, the following reviewed and quality-assured data are available from the following Shell meteorological network for use in dispersion modeling of the Beaufort and Chukchi Sea regions:

Beaufort Sea

- Badami: August 15, 2009 – November 2010 (16 months); data available for 2009 and 2010 drilling seasons
- Reindeer Island tower: April 26, 2009 – November 2010 (19 months); data available for 2009 and 2010 drilling seasons
- Reindeer Island buoy: August 5 – September 3, 2009 (approximately 1 month); and August 18 – September 24, 2010 (approximately 1 month)
- Endeavor Island: May 2010 – November 2010 (7 months)
- Beaufort Sea buoy: August 23 – October 13, 2009 (approximately 1.5 months); and August 13 – October 11, 2010 (approximately 2 months)

Chukchi Sea

- Wainwright: November 2008 – September 2010 (23 months); data available for the entire 2009 drilling season
- Point Lay: June 1, 2010 – November 2010 (6 months)
- Chukchi Sea buoy: September 9 – November 6, 2008 (approximately 2 months); August 28 – September 30 (approximately 1 month); and July 21 – October 20, 2010 (approximately 3 months)

Currently, Reindeer Island is the most complete data set for an offshore location for use in dispersion modeling. Reindeer Island is a small, natural barrier island located in the Beaufort Sea roughly 14 km from the northern Alaska mainland. Endeavor Island is an island built by BP for the Endicott production facility and is located approximately 6 kilometers to the northeast of the mainland. The Beaufort and Chukchi Sea buoys were deployed to support exploration and survey activities. These data sets did not receive the same level of quality control and assurance as the other Shell data sets. Wainwright (Chukchi Sea coast) and Badami (Beaufort Sea coast) are the most complete data sets for onshore locations.

3.5.2 Meteorological Data for Use with AERMOD

Available data for both 2009 and 2010 are utilized for the impact analyses of all pollutants (e.g., PM_{10}, $PM_{2.5}$, CO, SO_2), except NO_2. Consistent with EPA's requirement (per the Guideline on Air Quality Models) that permit applicants utilize at least a year of site-specific data, Shell has modeled the *Kulluk* impacts using the most recent and complete year of meteorological (2009), ozone, and NO_2 background data available for the 1-hour NO_2 analyses. Shell is not considering incomplete data sets for 2010 for the 1-hour NO_2 analyses, given the complex forms of the new 1-hour NO_2 NAAQS, which utilize statistics/percentiles based on complete years of data and other data availability issues. Currently, there is no ozone data available in Beaufort Sea region, which are necessary for the 1-hour NO_2 analyses described in Section 3.9. The monitoring organization responsible for the Beaufort Sea ozone station at Barrow (NOAA) has indicated that there is a six-month lag between the dates of ozone data collection and when the data is made available to the public.

The details regarding the preparation of 2009 and 2010 meteorological data for input to AERMOD are complex. Thus, they are provided as Attachments B and C of this report. Data processing for both the Beaufort and Chukchi Seas are discussed, but only the Beaufort Sea meteorological data is used in this impact analysis for the *Kulluk*. Figure 3-5 provides wind roses for the Beaufort Sea meteorological data used in the impact analyses. The predominant wind directions for both the 2009 and 2010 meteorological data sets are from the east and east-northeast.

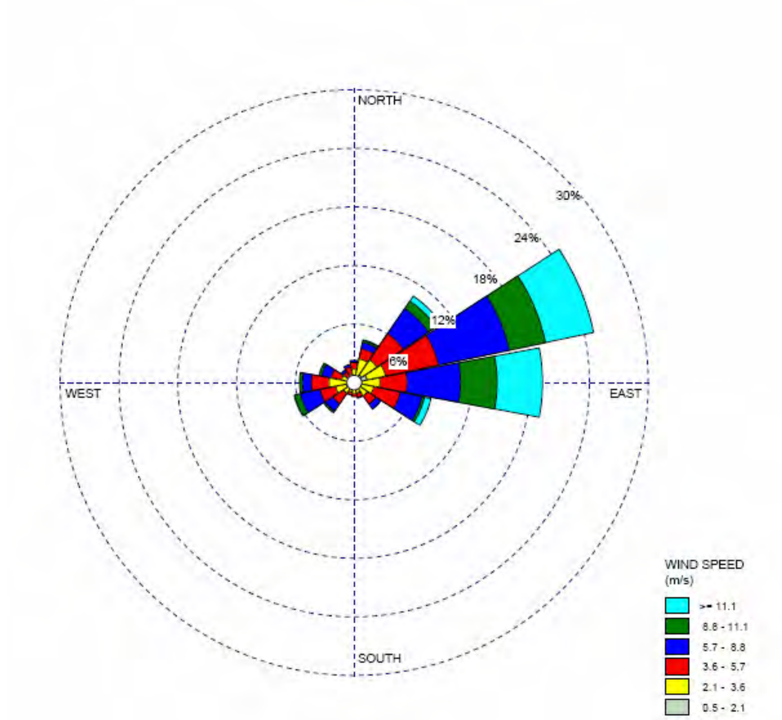
3.6 Ambient Air Boundary and Receptors

The ambient air standards are applicable at the ambient air boundary and beyond, which essentially is the nearest location to the *Kulluk* that the hypothetical public can approach. For this analysis, that boundary is established by public safety requirements and protection of the drilling project to be at least 500 meters from the *Kulluk* hull (i.e., approximately 540 meters from the center of the *Kulluk* for location purposes in the impact analysis). Within the 500 meters or greater area, Shell must have the unchallenged ability to transfer personnel and supplies, and to manage anchors, ice, and associated fleet vessel operations. This boundary is integral to the drilling operation; Shell cannot drill in the most prudent and safe manner without this zone of protection. Such a zone is consistent with plans approved by the Bureau of Ocean Energy Management, Regulation and Enforcement (BOEMRE). Because this boundary is on the water and there is no physical wall at 500 meters, Shell will prepare an Access Control Plan, which will include locating warning signs at its anchor points and will actively manage the area pursuant to applicable approvals to keep any unidentified vessels away.

Modeled receptors were placed on the ambient air boundary and spaced at approximately 25 meters around the boundary. To capture maximum impacts from the *Kulluk* and its associated fleet, receptors were placed every 100 meters out to 1 km from the center of the *Kulluk*. Receptors were spaced every 250-meters from 1 km to 5 km from the center of the *Kulluk* to cover all activity areas upwind and downwind of the *Kulluk*. An overview of the receptor grid used in the impact analysis is provided in Figure 3-6.

Figure 3-5: Wind Roses for the Beaufort Sea Meteorology Used in the Impact Analysis (July 1 – November 30)

2009



2010

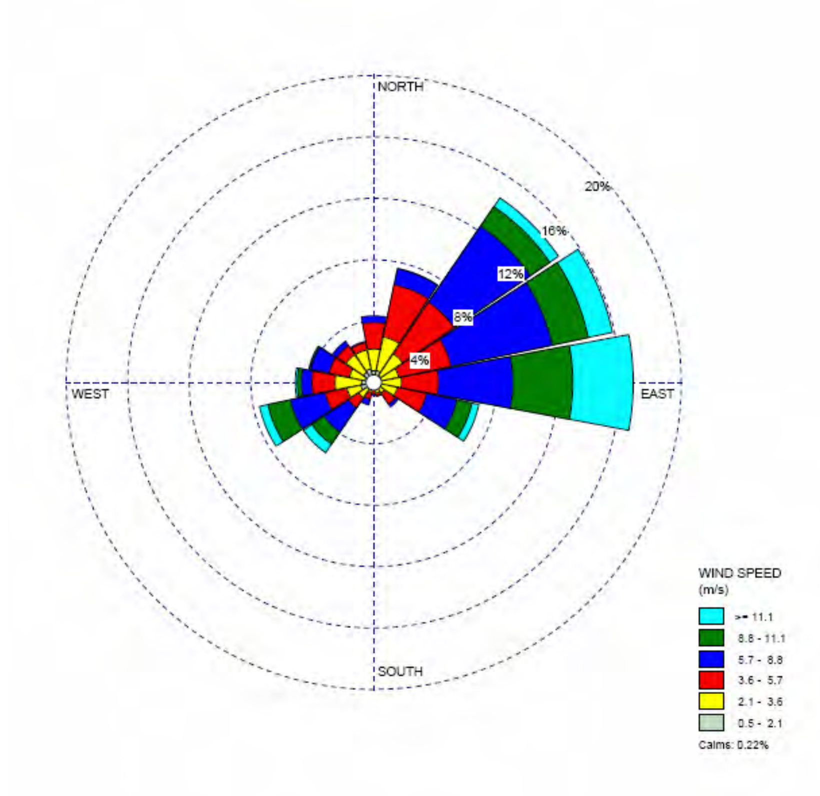
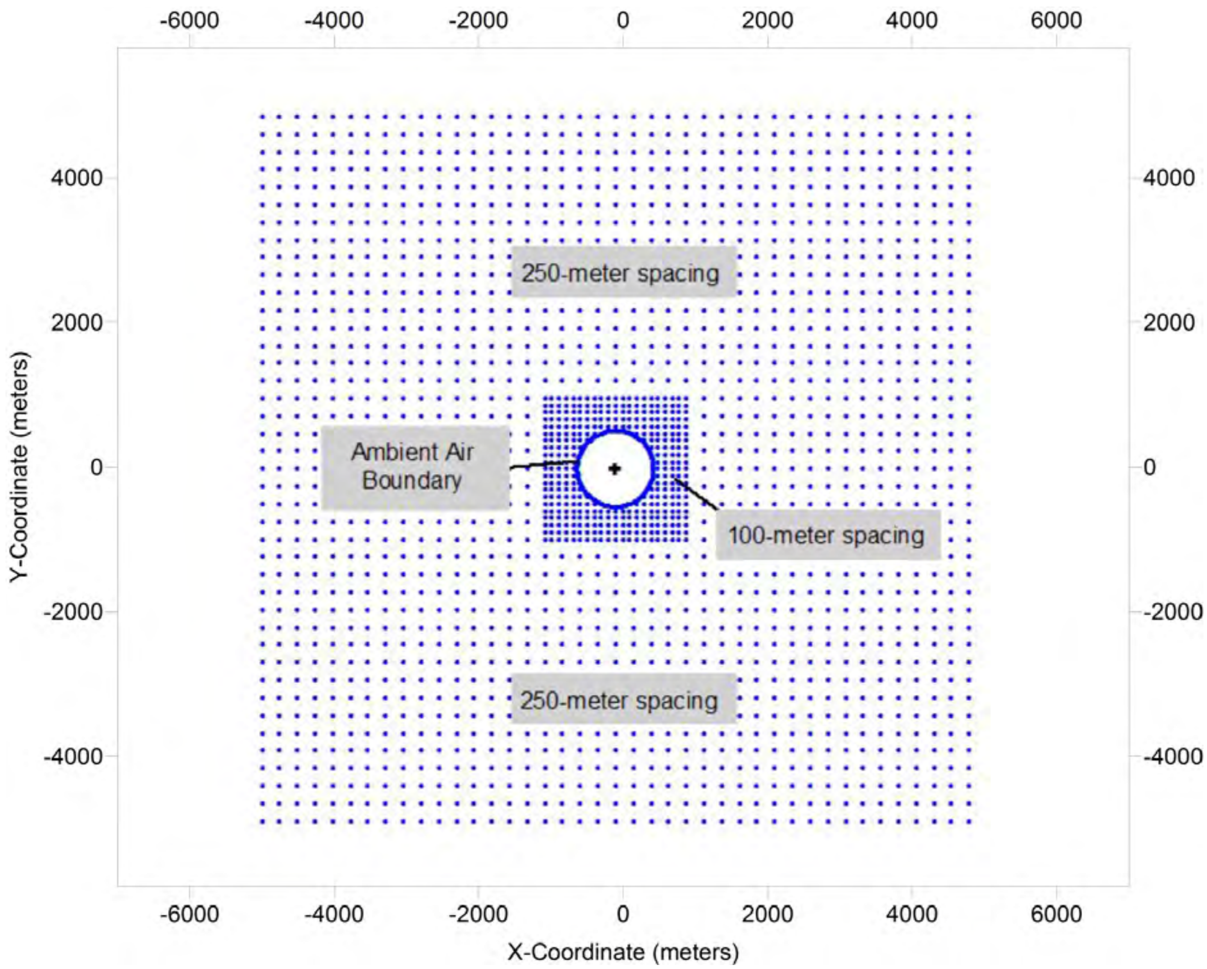


Figure 3-6: Overview of Receptor Grid Used in the Impact Analysis

(+ in the figure represents the *Kulluk*)



3.7 Background Concentrations

When comparing a project's impact to the NAAQS, an ambient background concentration is included. The background concentration represents impacts from natural and anthropogenic sources not included in the modeling analysis. EPA's Guideline on Air Quality Models (Appendix W to Part 51, paragraph 8.2.2) identifies two options for isolated sources like the OCS lease block locations addressed herein: 1) collect air quality data in the vicinity of the source, or 2) rely on regional monitoring data.

Ideally, one would locate monitoring stations close to the potential drilling locations, but lack of monitoring sites, safety concerns, hazardous conditions, limited infrastructure/power, and so on, make it infeasible to monitor background concentrations at the Shell OCS lease blocks or even at the nearest shoreline. Given the remote offshore project locations and lack of ambient data from these locations, onsite or near-site data are not available.

According to the Guideline on Air Quality Models (40 CFR 51, Appendix W, Section 8.2.2c), if there are no monitors located in the vicinity of the source, a "regional site" may be used to determine background concentrations. A "regional site" is one that is located away from the area of interest, but is impacted by similar natural and distant man-made sources. Note that as part of the 2009 OCS PSD permits for the *Discoverer* drillship, EPA approved the use of shore-based air quality background measurement for Shell's proposed operations in both the Beaufort and Chukchi Seas. The shore-based monitors are exposed to more natural and man-made sources than would be experienced at OCS sites, so the on-site baseline concentrations would be expected to be lower. The application of onshore data to offshore areas provides a conservative representation of air quality in the area covered by the OCS leases.

Figure 3-7 is a map showing the locations of currently operating and historical ambient monitoring stations on the North Slope.

For the 2009 and 2010 drilling seasons, the following ambient background data shown in Table 3-6 are available and were utilized to estimate background concentrations at offshore locations in the Beaufort Sea. Since this data was collected on land, it is likely to be higher than baseline concentration three miles or more in the Beaufort Sea where there are fewer natural and anthropogenic sources. For the 1-hour NO_2 analyses, hourly background concentrations are added to hourly modeled impacts on an hour-by-hour basis to determine a total impact value. For the 24-hour $PM_{2.5}$ analyses, daily background concentrations are added to daily modeled impacts on a day-by-day basis to determine a total impact value. For the other ambient standards, (e.g., $PM_{10,}$ CO, and SO_2), background concentrations are added to modeled impacts unpaired in time.

Note that data from the BP Exploration, Inc. (BPX) Liberty PSD monitoring program (Endicott Island) and other monitors near Prudhoe Bay represent estimates of regional background concentrations for offshore locations in the Beaufort Sea and were approved by EPA for use in the 2009 PSD permits for the *Discoverer* drillship. Shell's Badami monitoring station (previously operated by BPX in 1999) began operating again in August 2009 and provides another data source to estimate offshore background concentrations for the Beaufort Sea region.

Background concentrations utilized for the modeling analyses coincide with the drilling season to be permitted (e.g., July through November) and do not include data from the months when Shell OCS drilling will not occur.

Figure 3-7: Ambient Monitoring Stations on the North Slope

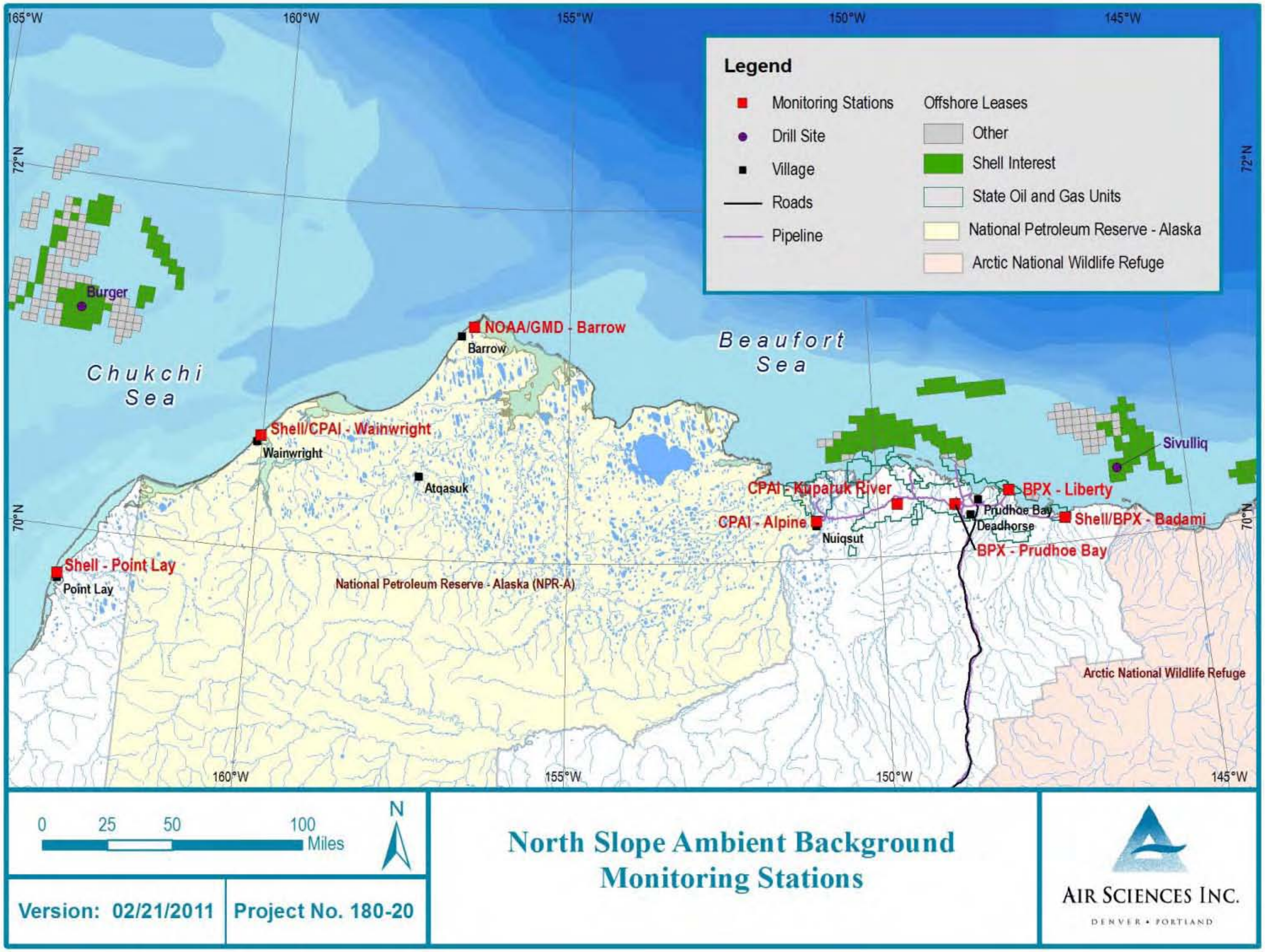


Table 3-6: Beaufort Sea Background Data Sources and Use of Background Data

Pollutant	Averaging Period	Background Concentration ($\mu g/m^3$)	Data Source
NO_2	1-hour	Varies hourly [1A]	Badami (7/2009 - 11/2009) filled with Prudhoe Bay Pad A when missing.
	Annual	Varies hourly [1A]	Badami (7/2009 - 11/2009) filled with Prudhoe Bay Pad A when missing.
PM_{10} [3]	24-hour	55.1	From Shell Discoverer Beaufort Sea PSD Permit Application (Revised September 2009); BPX Prudhoe Bay area (2006, 2007).
$PM_{2.5}$	24-hour	Varies daily [1B]	Badami (8/2009 - 11/2009 and 7/2010 - 11/2010) filled with the two-year average of 98th percentile daily values (7 $\mu g/m^3$) when missing.
	Annual	Varies daily [1B]	Badami (8/2009 - 11/2009 and 7/2010 - 11/2010) filled with the two-year average of 98th percentile daily values (7 $\mu g/m^3$) when missing.
SO_2 [3]	1-hour	13.0	BPX Liberty (7/2007 - 11/2007) [2]
	3-hour	11.4	
	24-hour	4.2	
	Annual	1.7	
CO [3]	1-hour	1,746	BPX Liberty (7/2007 - 11/2007) [2]
	8-hour	862	

[1A] Hourly NO_2 background is paired with hourly modeled impacts for the 1-hour NO_2 impact analyses.

[1B] Daily $PM_{2.5}$ background is paired with daily modeled impacts for the 24-hour $PM_{2.5}$ impact analyses.

[2] This is the same monitoring station utilized for SO_2 and CO background in the Shell Discoverer Beaufort Sea PSD Permit (Revised September 2009).

The background value presented is the highest concentration representative of the months of Shell's proposed open-water drilling season (July 1 - November 30).

[3] Short-term (i.e., 1-, 3-, 8-, 24-hour) background concentrations for PM_{10}, SO_2, and CO are conservatively assumed as the maximum values measured.

3.8 Modeling Approaches

As discussed in Section 3.1, for the leases in the Beaufort Sea, the impact components of the federal and Alaska regulations include requirements to address the NAAQS and the AAAQS (see Table 3-1 above. The most challenging ambient standards for Shell are the 1-hour NO_2 and 24-hour $PM_{2.5}$ NAAQS. More detailed discussions of the modeling approaches utilized for these two pollutants are provided in Sections 3.9 and 3.10 below.

3.9 Modeling Approach for 1-hour NO_2

3.9.1 Overview of EPA Tiered Approach to 1-hour NO_2 Modeling

Currently, the Guideline presents a three-tiered approach converting annual NOx impacts to annual NO_2 impacts for comparison to the annual NO_2 NAAQS. In a June 28, 2010 EPA memo [7], the applicability of the Guideline is discussed in the context of modeling for compliance with the new 1-hour NO_2 standard. While the new 1-hour NO_2 NAAQS is defined relative to ambient concentration of NO_2, the majority of NOx emissions for stationary and mobile sources are in the form of NO rather than NO_2. Given the role of NOx chemistry in determining ambient impact levels of NO_2 based on modeled NOx emissions, the Guideline recommends a three-tiered approach to modeling NO_2 impacts. According to the June 28, 2010 EPA memo, a summary of EPA's three-tiered approach in respect to the 1-hour NO_2 NAAQS is as follows:

- Tier 1: Total conversion of NO to NO_2 – applies to the 1-hour NO_2 standard without any additional justification,
- Tier 2: Multiply Tier 1 result by empirically-derived NO_2/NOx ratio, with 0.75 as the annual national default ratio – may also apply to the 1-hour NO_2 standard in many cases, but some additional consideration will be needed in relation to an appropriate ambient ratio for peak hourly impacts since the current default ambient ratio is considered to be representative of "area wide quasi-equilibrium conditions," and
- Tier 3: "Detailed screening methods" – will continue to be considered on a case-by-case basis for the 1-hour NO_2 standard.

While the Guideline specifically mentions OLM as a detailed screening method under Tier 3, EPA also considers the PVMRM discussed under Section 5.1.j of the Guideline to be in this category at this time. Both of these options account for ambient conversion of NO to NO_2 in the presence of ozone.

The OLM and PVMRM methods are both available as non-regulatory default options within the EPA-preferred AERMOD dispersion model. As a result of their non-regulatory default status, pursuant to Sections 3.1.2.c, 3.2.2.a, and A.1.a(2) of the Guideline, application of AERMOD with the OLM or PVMRM option is not considered a "preferred model" and can therefore be used, but its use needs to be justified and approved by the EPA Regional Office on a case-by-case basis.

It is Shell's understanding from verbal discussions that R10 does not object to the use of AERMOD with PVMRM chemistry for offshore OCS modeling of 1-hour NO_2 impacts in both the

[7] Fox, Tyler, EPA – Air Quality Modeling Group. [Memo Regional Air Division Directors]. Applicability of Appendix W Modeling Guidance for the 1-hour NO_2 National Ambient Air Quality Standard. June 28, 2010.

Beaufort and Chukchi Seas. Thus, Shell has utilized a Tier 3 modeling approach with AERMOD as described below.

3.9.2 Data Necessary to Utilize PVMRM Chemistry

According to EPA, key model inputs for both the OLM and PVMRM options in AERMOD are the in-stack ratios of NO_2/NOx emissions and background ozone concentrations. Shell has the necessary ambient ozone data and in-stack NO_2/NOx ratios to utilize the PVMRM chemistry in a Tier 3 modeling approach. Recognizing the potential importance of the in-stack NO_2/NOx ratio for hourly NO_2 compliance demonstrations, Shell has collected in-stack ratios from many diesel engines and the incinerator and heaters and boilers that could be used for the *Discoverer* drilling program. These measured ratios provide engine category averages for the *Kulluk*. The NO_2/NOx ratios measured from the recent stack testing program for the *Discoverer* drillship diesel engines are provided in Attachment D.

For the diesel engines, the average NO_2/NOx ratios for the highest load tests of all sources (i.e., 80-100 percent load) are 0.117 while the average NO_2/NOx ratios for the moderate load tests (i.e., 50-60 percent load) are 0.136. The range from all the tests is 0.042 to 0.469. All the tests were performed by the same contractor, which should eliminate contractor-methods-related differences. Tests for the HPU engines and MLC compressors in Attachment D results show high ratios of 0.27 to 0.47, which are for the Caterpillar C15 (a Tier 2 engine) and the Detroit 8V71 engine (a pre-tier engine). Both manufacturer and generation of design of these two engines are different and furthermore, tests on a second Detroit 8V71, on the cementing unit, show ratios ranging from 0.05 to 0.26, which are about half the ratios of the first tests. Neither the Shell engineer on-site during these high ratio tests, nor the testing company, can offer a reason for these few high ratios scattered in with many with low ratios. So, it appears that there is a high degree of variability in the NO_2/NOx ratios and the average ratios (segregated by tailpipe control device, discussed below) were used for all diesel emissions for the *Kulluk* impact analysis.

R10 has asked that Shell further evaluate the *Discoverer* NO_2/NOx data to determine if there is an effect of tailpipe emission controls on the NO_2/NOx ratios. Upon evaluation it was determined that NO_2/NOx ratios for sources with controls are higher than sources without controls installed. At higher loads (90 – 100 percent load), the average NO_2/NOx ratios for various control technology combinations are:

- 0.158, Catalyzed Diesel Particulate Filter (CDPF) only
- 0.176, CDPF + oxidation catalyst
- 0.060, SCR + oxidation catalyst (80-100 percent load)
- 0.066, no tailpipe controls

Because of the similarity of the CDPF and oxidation catalyst averages, they are considered essentially the same in ratio. The SCR data are given less credibility because of the few samples. So, for impact evaluation purposes, Shell has used NO_2/NOx ratios for two engine groups: those with controls and those without controls. *Kulluk* engine sources with tailpipe emission controls are assigned an average NO_2/NOx ratio of 0.176 which is the highest ratio for any of the control technology combinations listed above, and higher ratios lead to higher impact estimates. So this is another form of impact estimation to the high side of actual. For *Kulluk* engine sources without controls, an average NO_2/NOx ratio of 0.066 is used. The average NO_2/NOx ratio of the available tests for the heaters/boilers is 0.041 and the ratio measured for the incinerator is 0.023 and these values are used in the *Kulluk* impact analysis for these sources.

3.9.3 Pairing of Modeled Impacts and Background NO_2 Data

In EPA's June 28, 2010 memo regarding 1-hour NO_2 modeling issues, EPA notes that the form of the new 1-hour NO_2 standard has implications regarding appropriate methods for combining modeled ambient concentrations with monitored background concentrations for comparison to the NAAQS in a modeling analysis. EPA recommends that the modeled contribution to the ambient impact assessment for the 1-hour NO_2 standard should follow the form of the standard based on the 98^{th} percentile of the annual distribution of daily maximum 1-hour concentrations averaged across the number of years modeled. A "first tier" assumption that may be applied without further justification is to add the overall highest hourly background NO_2 concentration from a representative monitor to the modeled design value, based on the form of the standard, for comparison to the NAAQS.

EPA allows additional refinements to this "first tier" approach based on some level of temporal pairing of modeled and monitored values to be considered on a case-by-case basis, with adequate justification and documentation. The next two subsections explain Shell's rationale behind why pairing modeled and monitored values is justified and is conservative (i.e., there are no NO_2 sources for offshore in the OCS so use of on-land background values is already very conservative).

Shell believes that temporal pairing of background and modeled values is appropriate from a technical perspective and is consistent with the form of the 1-hour NO_2 standard, and R10 indicated that it was open to this approach beginning at an August 12, 2010 Shell/EPA meeting. The Shell modeling analyses already has built-in worst-case assumptions, including the use of PTE emissions (rather than actual emissions) and impact modeling for the entire season at a single location (rather than at multiple well locations).

The NO_2 baselines used to pair hourly modeled impacts with hourly background are representative of the regional conditions in Beaufort Sea. The NO_2 data are regional in nature since there are few and only small local sources of NO_2 or hydrocarbons (forming ozone) near the monitoring stations. Also, these on-land measurements are on the high side of representativeness of background concentrations on the OCS because the only sources of these pollutants are on land, nearer to the monitoring stations. Figure 3-8 is a plot of the daily maximum 1-hour NO_2 values measured at Badami for the proposed 2009 drilling season. Measured NO_2 concentrations at Badami on the Beaufort Sea coast are consistently very low and are only higher than one tenth of the 1-hour NAAQS level (i.e., 19 $\mu g/m^3$) for 11 hours out of more than 3,300 hours measured (i.e., 0.3 percent of the time). The few elevated concentration measurements at Badami are likely the result of impacts from local, shore-based sources. Thus, the use of these higher hourly measurements at locations on the OCS is highly conservative since there are no regional emission sources of NO_2 at the OCS locations.

EPA R10 Precedent Allowing Use of Shore-Based Measurements at OCS Locations

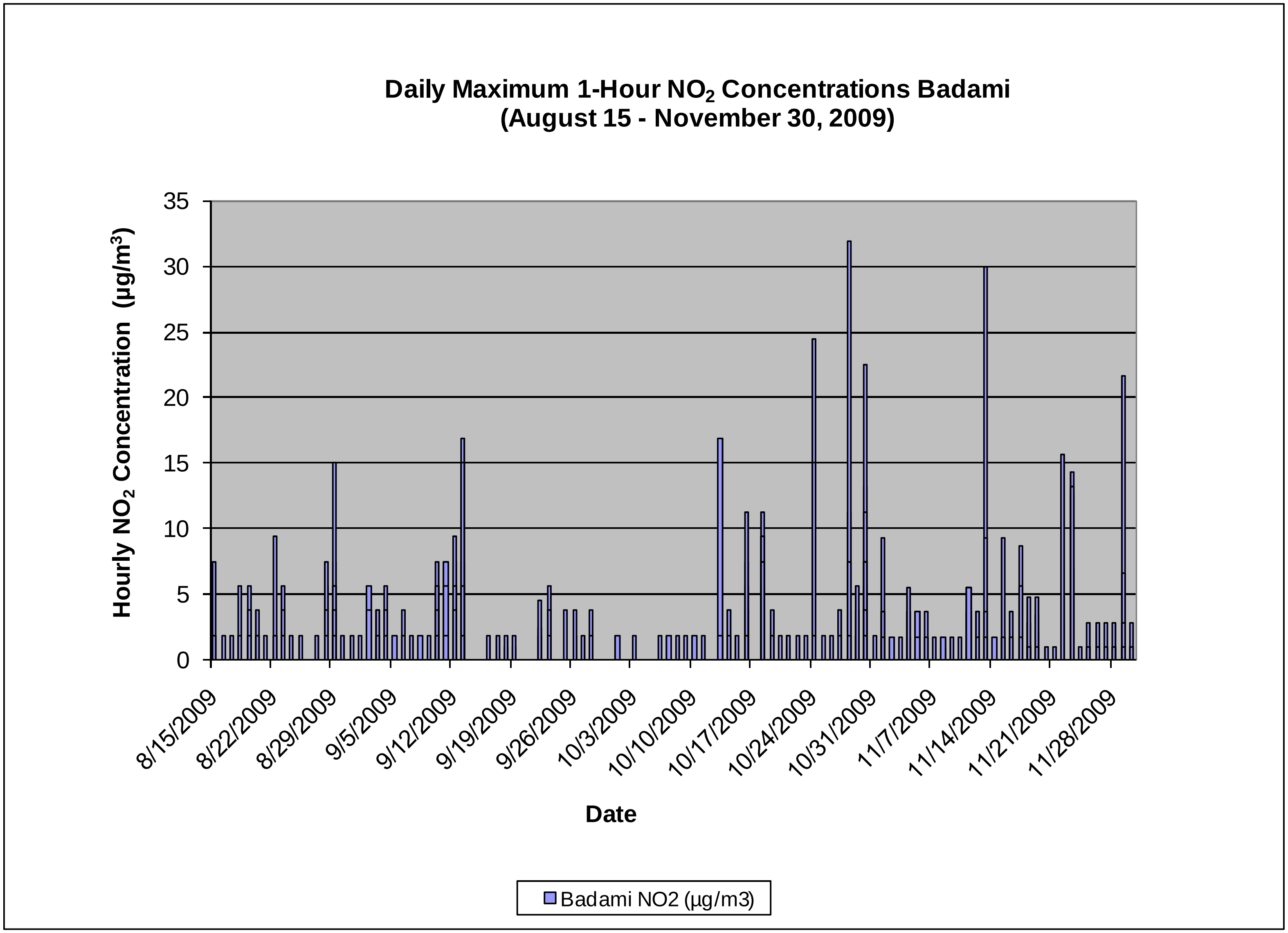
As part of the recent OCS PSD permit for the *Discoverer* drillship, EPA approved the use of shore-based air quality background measurement for Shell's proposed operations in the Beaufort and Chukchi Seas.

From EPA's statement of basis on the *Discoverer*, Chukchi Sea PSD permit:

> Shell relied on data collected at a monitoring station in Wainwright, Alaska, one of the few locations on the coast of the Chukchi Sea that has even limited infrastructure. There are no islands, platforms or infrastructure in the Chukchi Sea on which to install, operate and maintain ambient air quality monitoring equipment. Wainwright is a rural community on the shores of the Chukchi Sea with a population of around 500. There are a number of air pollution sources in Wainwright, such as a diesel-fired utility electric power plant, a fuel storage facility, airport, residential heating, vehicle exhaust, and unpaved roads. Importantly, Wainwright experiences arctic weather conditions similar to those of the Chukchi Sea. While the Wainwright monitoring station will be somewhat influenced by local sources, EPA believes that it provides a conservative representation of air quality in the area covered by Shell's leases in Lease Area 193 because of the relative closeness of Wainwright to the Shell leases, the relative lack of air pollution sources in Wainwright and the area covered by Shell's leases, and the similarity of the meteorology in Wainwright and the area covered by Shell's leases.

In coordination with EPA, Shell has installed air quality monitoring stations at several shore-based locations that have the necessary infrastructure for air quality monitoring (e.g., Wainwright, Point Lay, Badami), and hourly NO_2 data are measured at each of these stations.

Figure 3-8: Plot of Daily Maximum 1-Hour NO_2 Concentrations at Badami – 2009 Drilling Season



Shell asserts that temporal pairing of hourly modeled NO_2 impacts with hourly background values is an appropriate technical approach to assessing total modeled impacts. As stated above, EPA has allowed the use of conservative onshore background concentrations to represent offshore locations. Thus, for the Beaufort Sea, Shell has utilized paired hourly modeled NO_2 impacts with hourly onshore background NO_2 (Badami for the Beaufort Sea with Prudhoe Bay area Pad A data when Badami data is missing) to determine a total NO_2 concentration for each hour modeled for the 2009 drilling season. Consistent with the form of the new 1-hour NO_2 NAAQS, the maximum daily 1-hour NO_2 values are determined, and the 98th percentile of these maximum daily 1-hour impacts are compared to the 1-hour NO_2 NAAQS (see Section 3.12).

Data Filling Procedures to Generate Complete Hourly NO_2 and O_3 Data Sets

For NO_2 modeling analyses, both NO_2 and Ozone (O_3) data are required. For the Beaufort Sea analyses, hourly ozone concentrations on the North Slope of Alaska (available alternate stations' hour-by-hour values concurrent with the meteorological data) were evaluated for use in the modeling analyses. For 2009, ozone data are currently available from Barrow and the Prudhoe Bay area (e.g., BP's Pad A station). For the Beaufort Sea NO_2 analyses, hourly NO_2 data from Badami were used. To generate a complete NO_2 background data set, the following approach was taken: use the hourly NO_2 data from Badami when available. If Badami data is missing, fill with Prudhoe Bay area Pad A station. When data from both stations are missing, two hours or less of missing data are filled by interpolation. When more than two hours of data are missing, fill the missing data with the highest hourly value within 24 hours of the missing hour.

A summary of the data sources utilized for paired NO_2 modeling are provided in Table 3-7.

Table 3-7: Summary of Data Sources for Paired NO_2 Modeling

Pollutant	Year	Data Source for Paired Modeling Beaufort Sea
NO_2	2009	**Badami filled with Pad A when missing.** Two or less hours of missing data filled by interpolation. When larger periods of missing data exist, fill with the highest hourly value +/- 24 hours from the missing value (largest missing period is one 18 hour period).
O_3	2009	**Barrow and Pad A;** highest values from either station hour-by-hour.

3.10 Modeling Approach for $PM_{2.5}$

For modeling of 24-hour $PM_{2.5}$ impacts, Shell has utilized the same models and meteorological data described in Section 3.9 for 1-hour NO_2 impacts, but the modeling of 24-hour $PM_{2.5}$ did not include the OLM and PVMRM chemistry methods, which are specific to NO_2 modeling.

As previously mentioned, the highest 24-hour $PM_{2.5}$ impacts are calculated in a similar way to the 1-hour NO_2 impacts where hourly $PM_{2.5}$ impacts are processed over two 120-day emission sequences and the 98th percentile 24-hour average $PM_{2.5}$ concentration are determined from the hourly modeled impacts. Similar to the 1-hour NO_2 analyses, which considered paired modeled and background values, the daily 24-hour $PM_{2.5}$ impacts are paired with the daily $PM_{2.5}$ background concentrations to determine the 98th percentile impacts from the two modeled 120-day sequences. To generate a complete $PM_{2.5}$ background data set, missing days of $PM_{2.5}$ data are filled with the two-year average 98th percentile of the measured daily $PM_{2.5}$ concentrations (also see Table 3-6).

A summary of the data sources utilized for paired $PM_{2.5}$ modeling are provided in Table 3-8.

Table 3-8: Summary of Data Sources for Paired $PM_{2.5}$ Modeling

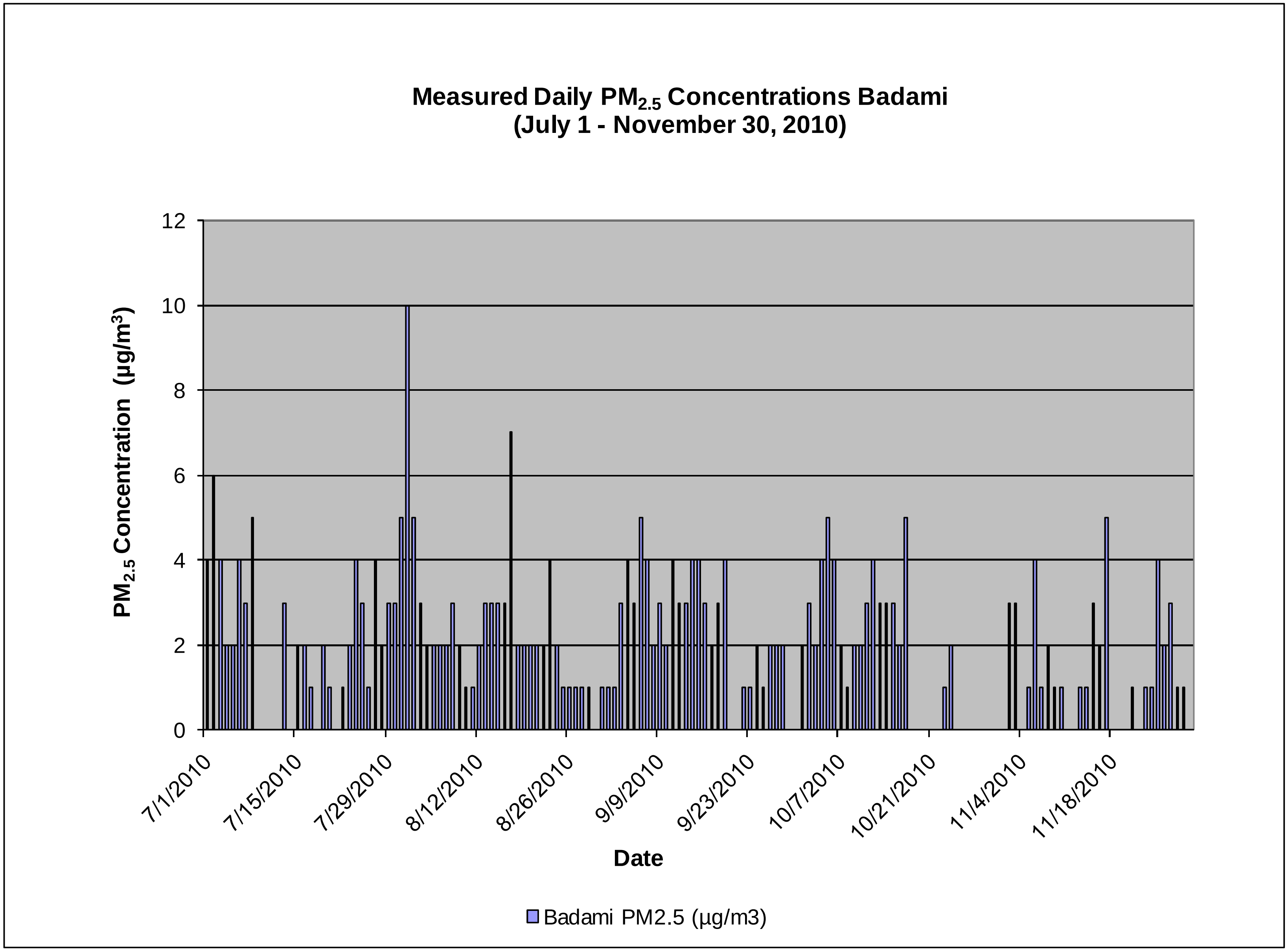
Pollutant	Year	Data Source for Paired Modeling Beaufort Sea
$PM_{2.5}$	2009 2010	**Badami** (8/2009 - 11/2009 and 7/2010 - 11/2010) filled with the two-year average of the 98th percentile daily values (7 $\mu g/m^3$) when missing.

Pairing of Modeled Impacts and Background $PM_{2.5}$ Data

Shell believes that temporal pairing of background and modeled values is appropriate from a technical perspective and is consistent with the form of the 24-hour $PM_{2.5}$ standard. The Shell modeling analyses already have built-in worst-case assumptions, including the use of PTE emissions (rather than actual emissions) and impact modeling for the entire season at a single location (rather than at multiple well locations). In addition, the Shell source location configurations are already designed to be worst-case.

The $PM_{2.5}$ baselines used to pair daily modeled impacts with daily background are representative of the regional conditions in Beaufort and Chukchi Seas. The $PM_{2.5}$ data are regional in nature since there are few and only small local sources of $PM_{2.5}$ near the monitoring stations. Also, these on-land measurements are on the high side of representativeness of background concentrations on the OCS because the only sources of these pollutants are on land, nearer to the monitoring stations. Figure 3-9 is a plot of the daily $PM_{2.5}$ measured at Badami for the proposed 2010 drilling season. Measured $PM_{2.5}$ concentrations at Badami on the Beaufort Sea coast are consistently very low and are only higher than 20 percent of the 24-hour NAAQS level (i.e., 5 $\mu g/m^3$) for 3 days out of 139 days measured (i.e., 2 percent of the time). The few elevated concentration measurements at both monitoring stations are likely the result of impacts from local, shore-based sources (e.g., fugitive dust). Thus, the use of these higher daily measurements at locations on the OCS is highly conservative since there are no regional emission sources of $PM_{2.5}$ at the OCS locations.

Figure 3-9: Plot of Measured Daily $PM_{2.5}$ Concentrations at Badami – 2010 Drilling Season



3.11 Modeling Approach for Other Pollutants

For other pollutants with less stringent ambient standards, such as CO, NH_3, and SO_2, Shell has pursued a simpler, single modeling run (not separate hourly runs like NO_2, $PM_{2.5}$ and PM_{10}), which are used to calculate impacts. With this modeling approach, the model internally perform averaging calculations which eliminates the setup, post-processing, and EPA review associated with individual hourly model runs used to determine modeled impacts.

Note that lead and reduced sulfur compounds emissions from the *Kulluk* are insignificant and are not evaluated in the modeling analyses. The only source of sulfur emissions are from the sulfur in the diesel fuel used on the *Kulluk* and its associated fleets. Because all the fuel is low-sulfur fuel, and the processes using the diesel fuel are oxidation processes, the emissions of reduced sulfur compounds will be negligible and therefore ambient concentrations will also be negligible (same assumption as Shell *Discoverer* PSD permit applications in 2009).

For the simplified analysis for pollutants with less stringent ambient standards (CO, NH_3, SO_2) numerous conservative assumptions were utilized. The wind direction was assumed to blow from the same wind direction for every hour of the proposed drilling season (analogous to a screening modeling exercise). As shown in Figure 3-10, the OSR and ice management/anchor source configurations were fixed in space (no variation with wind direction) for every single hour of the proposed drilling season and were aligned so that the maximum combination of plumes from the ice management/anchor handler, resupply ship, *Kulluk*, and OSR sources would occur for every hour (i.e., all sources are in a single line and don't vary spatially). For all hours, the hourly plume heights for the fleet sources were based on the lowest plume height predicted for any hour in the meteorological data sets. In addition, the smallest sigma Z values were utilized regardless of meteorological conditions (consistent with the *Discoverer* 2009 PSD, screening modeling approach). In addition, the analysis considered all sources operating simultaneously at maximum emissions for every hour of the drilling season. Even with these very conservative assumptions the modeled impacts for CO, NH_3, SO_2 are in compliance with the NAAQS/AAAQS as shown in Section 3.12.

3.12 Impact Modeling Results

A summary of the maximum modeled impacts of the *Kulluk* and associated fleet plus background concentrations for comparison to the NAAQS/AAAQS is provided in Table 3-9. These results show that Shell's proposed *Kulluk* Beaufort Sea exploratory drilling program will comply with the NAAQS/AAAQS. Note that all maximum impacts are located on the ambient air boundary.

Figure 3-10: Source Configuration for the Ammonia, CO, and SO_2 Impact Analyses

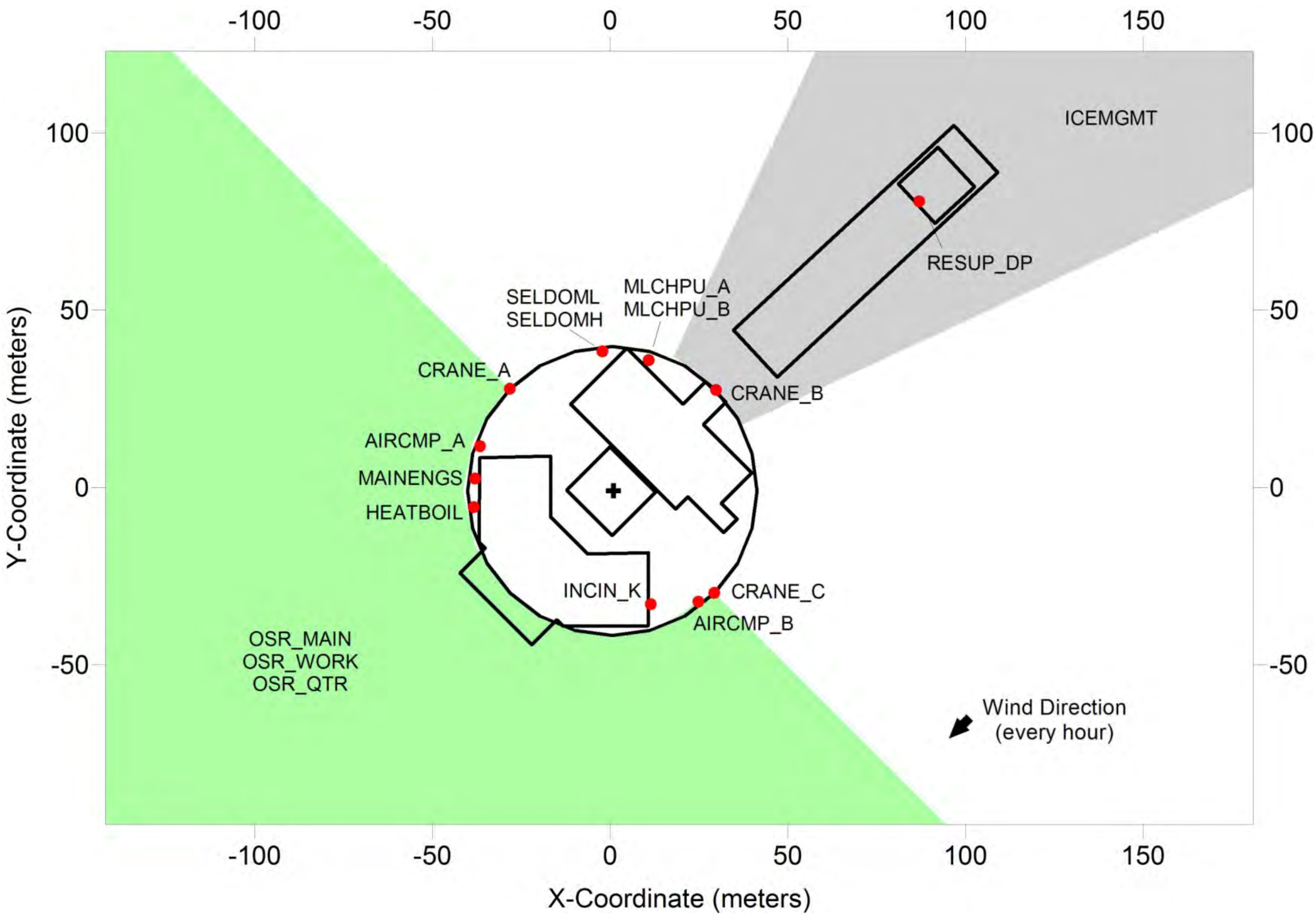


Table 3-9: Summary of Maximum Modeled Impacts

Pollutant	Averaging Period	Utilize Emissions Sequence?	Pair Background In Time?	Max. Modeled Impact - Shell Only at or Beyond Ambient Air Boundary [1A, 2A] ($\mu g/m^3$)	Background Concentration ($\mu g/m^3$)	Max. Total Impact [3, 1B, 2B] ($\mu g/m^3$)	AAAQS/ NAAQS ($\mu g/m^3$)	Comply?
NO_2	1-hour	Yes	Yes	60.0		108.7	188	Yes
	Annual [1B]		Yes	9.8	2.4	4.0	100	Yes
$PM_{2.5}$	24-hour	Yes	Yes	7.0		14.0	35	Yes
	Annual [1B] Yes		Yes	2.5	4.7	2.4	15	Yes
PM_{10}	24-hour	Yes	No	20.6	55.1	75.7	150	Yes
SO_2	1-hour Yes	No	No	23.548.7	13.0	36.5	196	Yes
	3-hour	No	No	16.0	11.4	27.4	1,300	Yes
	24-hour	No	No	10.8 7.0	4.2	15.0	365	Yes
	Annual [2B]		No	5.5	1.7	4.0	80	Yes
CO	1-hour	No	No	1,273	1,746	3,019	40,000	Yes
	8-hour No	No	No	714	862	1,576	10,000	Yes
NH_3	8-hour	No	No	6.6	---	6.6	2,100	Yes

1A Impact analyses for NO_2, $PM_{2.5}$, and PM_{10} span all 5 months of potential drilling activity (July 1 through November 30) using two 120-day emissions sequences to eliminate bias in the meteorological data; The highest impacts from the two 120-day sequences are shown.

1B For the total annual impact values, the 120-day period average impacts (Shell-only impact plus background) for NO_2 and $PM_{2.5}$ are adjusted to annual impacts by taking into account the periods of the year when Shell operations don't occur (i.e., multiply the 120-day average impacts by 0.329 (120 drilling days out of 365 days in a year)).

2A Impact analyses for SO_2, CO, and NH_3 span all 5 months (153 days) of potential drilling activity (July 1 through November 30) using a single, worst-case configured model run (153 days) without consideration of emissions sequencing or intermittent source operations.

2B The 153-day period Shell-only average impacts for SO_2 are adjusted to annual impacts by taking into account the periods of the year when Shell operations don't occur (i.e., multiply the 153-day Shell-only average impacts by 0.419 (153 drilling days out of 365 days in a year)) and are then added to the background concentration.

3 Total modeled impact is the sum of the highest modeled impact (from either 2009 or 2010) plus background concentrations. For NO_2 and $PM_{2.5}$, the 98[th] percentile values consistent with the form of the NAAQS are presented. For all other pollutants, the maximum modeled impacts are presented.

Also note that impacts between the two 120-day modeled sequences (July 1 – October 28 and August 3 – November 30) for NO_2, $PM_{2.5}$, and PM_{10} are very similar. Total impacts from NO_2, $PM_{2.5}$, and PM_{10} for both sequences for 2009 and 2010 are shown in Table 3-10 and indicate a variation of no more than four micrograms over any modeled sequence for any of the three pollutants. This model sensitivity test is based on an analysis of nearly 29,000 hourly model runs for the three pollutants.

All impacts for all sequences are well below the NAAQS/AAAQS and any variation between the sequences is only a small fraction of the NAAQS/AAAQS. Shell concludes that the impacts from these two sequences eliminate possible bias in the meteorological data and sufficiently bound impacts from the proposed Beaufort Sea exploratory drilling program while accounting for realistic operating/emission scenarios to determine impacts consistent with the 98th percentile form of the 1-hour NO_2 and 24-hour $PM_{2.5}$ NAAQS/AAAQS.

Table 3-10: Comparison of Highest Total Impacts for Pollutants Modeled with Emissions Sequences

Pollutant	Averaging Period	Highest Total Impact (μg/m³) at or Beyond Ambient Air Boundary [1] 2009 - "A"	2009 - "B"	2010 - "A"	2010 - "B"	NAAQS (μg/m³)	Highest Impact As Percentage of NAAQS (%)
NO_2	1-hour [2]	105.3	108.7	---	---	188	58%
	Annual	4.0	3.9	---	---	100	4%
$PM_{2.5}$	24-hour [2]	14.0	11.3	11.6	11.6	35	40%
	Annual	2.4	1.8	1.7	1.6	15	16%
PM_{10}	24-hour	72.0	75.7	75.7	72.8	150	50%

1 The highest impacts from the two 120-day sequences are shown:
Sequence "A" = July 1 through October 28, Sequence "B" = August 3 through November 30.

2 98th percentile impact values.

The nearest coastal villages to the OCS lease blocks are Nuiqsut, Deadhorse, and Kaktovik, which are located 37, 32, and 14 kilometers from the nearest OCS lease blocks, respectively (see Figure 3-11). Table 3-11 provides a summary of the modeled impacts from the proposed *Kulluk* project at the nearest coastal village locations and shows that impacts are well below the NAAQS/AAAQS. Shell-only impacts are no higher than 5 percent of the NAAQS/AAAQS for any pollutant.

Figure 3-11: Map of the Nearest Villages on the Beaufort Coast Relative to the OCS Leases

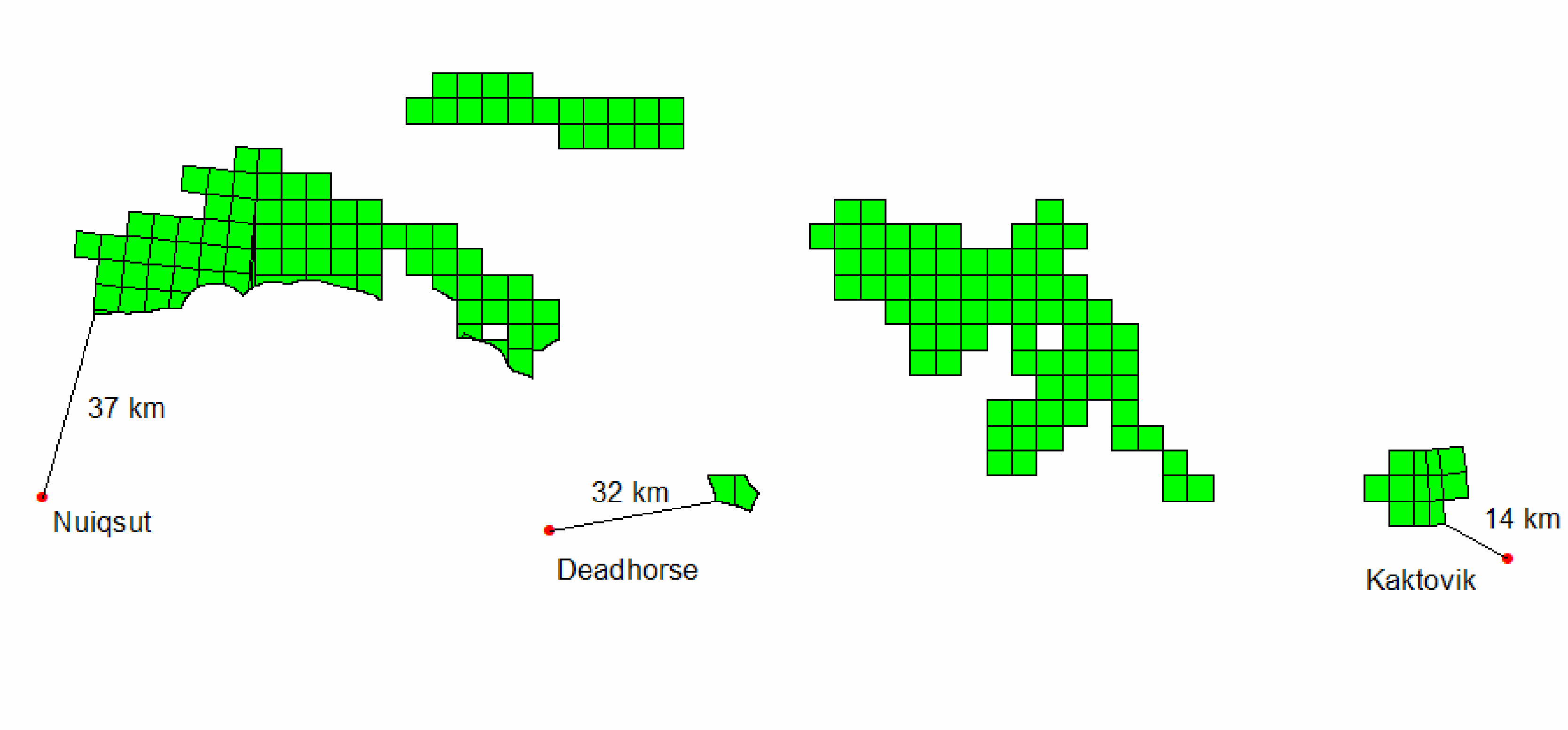


Table 3-11: Summary of Maximum Impacts at the Nearest Villages on the Beaufort Coast

Pollutant	Averaging Period	Max. Total Impact - Background Included (µg/m³) [3, 1B, 2B]			Shell Only Contribution to Max. Total Impact - (µg/m³) [1A, 2A]			AAAQS/ NAAQS (µg/m³)	Comply?	Highest Shell - Only Impact, Percentage of NAAQS/AAAQS (%)
		Nuiqsut	Deadhorse	Kaktovik	Nuiqsut	Deadhorse	Kaktovik			
NO_2	1-hour	22.2	24.5	26.0	6.6	0.02	0.01	188	Yes	4%
	Annual [1B]	0.8	0.9	0.9	0.1	0.2	0.2	100	Yes	0.2%
$PM_{2.5}$	24-hour	7.0	7.1	7.1	0.003	0.1	0.1	35	Yes	0.3%
	Annual [1B]	1.5	1.6	1.5	0.01	0.02	0.02	15	Yes	0.2%
PM_{10}	24-hour	55.4	55.7	55.6	0.3	0.6	0.5	150	Yes	0.4%
SO_2	1-hour	19.4	19.9	23.1	6.4	6.9	10.1	196	Yes	5%
	3-hour	16.2	16.6	19.5	4.8	5.2	8.1	1,300		1%
	24-hour	5.3	5.4	5.9	2.7	2.9	4.2	365	Yes	1%
	Annual [2B]	1.9	1.9	2.1	0.5	0.6	0.9	80Yes	Yes	1%
CO	1-hour	1,976	1,997	2,125	230	251	379	40,000	Yes	1%
	8-hour	999	1,012	1,089	137	150	227	10,000		2%
NH_3	8-hour	1.6	1.8	2.6	1.6	1.8	2.6	2,100	Yes	0.1%

Yes

1A Impact analyses for NO_2, $PM_{2.5}$, and PM_{10} span all 5 months of potential drilling activity (July 1 through November 30) using two 120-day emissions sequences to eliminate bias in the meteorological data;
The highest impacts from the two 120-day sequences are shown: Sequence "A" = July 1 through October 28, Sequence "B" = August 3 through November 30.

1B For the total annual impact values, the 120-day period average impacts (Shell-only impact plus background) for NO_2 and $PM_{2.5}$ are adjusted to annual impacts by taking into account the periods of the year when Shell operations don't occur (i.e., multiply the 120-day average impacts by 0.329 (120 drilling days out of 365 days in a year)).

2A Impact analyses for SO_2, CO, and NH_3 span all 5 months (153 days) of potential drilling activity (July 1 through November 30) using a single, worst-case configured model run (153 days) without consideration of emissions sequencing or intermittent source operations.

2B The 153-day period Shell-only average impacts for SO_2 are adjusted to annual impacts by taking into account the periods of the year when Shell operations don't occur (i.e., multiply the 153-day Shell-only average impacts by 0.419 (153 drilling days out of 365 days in a year)) and are then added to the background concentration.

3 Total modeled impact is the sum of the highest modeled impact (from either 2009 or 2010) plus background concentrations.
For NO_2 and $PM_{2.5}$, the 98th percentile values consistent with the form of the NAAQS are presented. For all other pollutants, the maximum modeled impacts are presented.

ATTACHMENT A

Spreadsheet of Source Usage and Emissions Estimation

shading represents requested limit to be demonstrated by documentation of each event

shading represents requested limit to be demonstrated by documentation of daily fuel consumption

shading represents requested limit to be demonstrated by documentation of weekly fuel consumption

Anticipated Kulluk Operating Maximums

Kulluk & Associated Fleet

Expected Operating Maximums	Limit		How Defined	How documented
MLC Drilling Activity	480	hrs/activity	20 days/activity	
Well Drilling Activity	1,152	hrs/activity	48 days/activity	
Cementing/Logging Activity	1,248	hrs/activity	52 days/activity	
Season maximum drilling duration as an OCS source (secure and stable for commencement of exploratory activity):	2,880	hrs/season	120 days/season	
Ice mgmt vessel use within 25 miles	38%			
OSR vessel annual fuel limit	60%	of daily maximum - annualized		
Quartering vessel annual fuel limit	60%	of daily maximum - annualized		
MLC Activity				
Generators (three units combined) combined	85%	capacity	System Limitation	
Crane (three units combined) maximum	40%	capacity	System Limitation	
Crane (three units combined) maximum	30%	of time (day)	Shell engineering estimate	
Well Drilling Activity				
Generators (three units combined) combined production maximum	85%	capacity	System Limitation	
Crane (three units combined) maximum	40%	capacity	System Limitation	
Crane (three units combined) maximum	30%	of time (day)	Shell engineering estimate	
Cementing/Logging Activity				
Generators (three units combined) combined	60%	capacity	Shell ORL	
Crane (three units combined) maximum	40%	capacity	System Limitation	
Crane (three units combined) maximum	50%	of time (day)	Shell engineering estimate	
All Activities - ORL				
Kulluk Incinerator limited to	12	hr/day	Shell ORL	manual - recording of time start and time stop
Kulluk emergency generator limited to	2	hr/30-days & hr/day		
Sulfur content of all stationary source engines on Kulluk	0.0100%	by wt.	Shell ORL	Kulluk fuel testing
Sulfur content of associated fleet	0.0100%	by wt.	Shell ORL	Fleet fuel
Annual NOx emissions recalculated as weekly rolling avg	250	ton/yr.	Shell ORL	
Ice Management Fleet Propulsion & Generation	100%	capacity	System Limitation	
Resupply ship in transport limited to	1,200	gal/1-way	Shell ORL	fuel consumption measurement
Resupply ship in DP mode limited to	4,800	gal/event	Shell ORL	fuel consumption measurement
Resupply ship resupply events limited to	24	rnd trip/season	Shell ORL	manual tracking
Resupply ship DP events limited to	24	hr/day=hr/event	Shell ORL	manual tracking
OSR Vessel p & g aggregate power:	2,600	kW		mfgr specifications
OSR Vessel p & g aggregate consumption:	2,800	gal/day	Shell ORL	fuel consumption measurement
Quartering vessel p & g aggregate power:	7,502	kW	Shell ORL	mfgr specifications
Quartering vessel p & g aggregate consumption:	4,800	gal/day	Shell ORL	fuel consumption measurement
OSR work boats	3,789	gallons/wk.	Shell ORL	fuel consumption measurement

OSR Boat Options

OSR vessel: Pt. Oliktuk/Arctic Endeavor

Quartering vessel: Nanuq

Work Boats

#1 OSR 34-foot	32	gal/hr
#2 OSR 34-foot	32	gal/hr
#1 OSR 47-foot	63	gal/hr
ALL	6	hr/day
ALL	5	day/week
ALL	100%	hourly fuel consumption

Diesel Engine Thermal Efficiency Assumptions

		Reference
7.1	lb/gal	AP42 Table 3.4-1; footnote a
7,000	Btu/hp-hr	<600 hp; AP42 Table 3.3-1 Footnote (a) ver. 10/96. >600 hp, AP42 Table 3.4-1 ver. 10/96

Conversions

0.1350	MMBtu/gallon
0.7457	kW / hp
1,000,000	Btu/MMBtu
453.6	g/lb
2,000	lb/ton
24	hr/day
168	hr/wk
2	one-way trips/ round trip
32.07	wt S
64.06	wt. SO2
2.00	wt. conversion of S to SO2

** seldom-used engines are those running < 4 hr/wk.

Anticipated Kulluk Operating Maximums

Kulluk & Associated Fleet (continued)

	Expected Operating Maximums	Controls NOx	Controls PM	Controls CO	Controls VOC	EF Reference NOx	EF Reference PM	EF Reference CO	EF Reference VOC
	Kulluk								
K_GE	Generation	Kulluk-SCR	OxyCat-Lg	OxyCat-Lg	OxyCat-Lg	4	7	7	7
K_HP	MLC HPU'S	None-Sm	OxyCat-Sm	OxyCat-Sm	OxyCat-Sm	2	8	8	8
K_AC	Air compressors	None-Lg	OxyCat-Lg	OxyCat-Lg	OxyCat-Lg	1	7	7	7
K_C	Cranes	None-Sm	OxyCat-Sm	OxyCat-Sm	OxyCat-Sm	2	8	8	8
K_H&	Heaters & Boilers	heat&boil	heat&boil	heat&boil	heat&boil	3	3	3	3
K_SU	Seldom-used units	None-Sm	None-Sm	None-Sm	None-Sm	2	2	2	2
K_EG	Emergency Generator	None-Sm	None-Sm	None-Sm	None-Sm	2	2	2	2
	Primary Ice Management								
IB_P&	Propulsion & Generation	SCR	OxyCat-Lg	OxyCat-Lg	OxyCat-Lg	5	7	7	7
IB_H&	Heaters & Boilers	heat&boil	heat&boil	heat&boil	heat&boil	3	3	3	3
IB_SU	Seldom-used units	None-Sm	None-Sm	None-Sm	None-Sm	2	2	2	2
	Secondary Ice Management / Anchor Handler								
AH_P&	Propulsion & Generation	SCR	OxyCat-Lg	OxyCat-Lg	OxyCat-Lg	5	7	7	7
AH_H&	Heaters & Boilers	heat&boil	heat&boil	heat&boil	heat&boil	3	3	3	3
AH_SU	Seldom-used units	None-Sm	None-Sm	None-Sm	None-Sm	2	2	2	2
	Resupply Ship - transport mode								
RST_P	Propulsion & Generation	None-Lg	None-Lg	None-Lg	None-Lg	1	1	1	1
RST_S	Seldom-used units	None-Sm	None-Sm	None-Sm	None-Sm	2	2	2	2
	Resupply Ship - DP mode								
RSDP_	Propulsion & Generation	None-Lg	None-Lg	None-Lg	None-Lg	1	1	1	1
RSDP_	Seldom-used units	None-Sm	None-Sm	None-Sm	None-Sm	2	2	2	2
	OSR vessel								
O_P&	Propulsion & Generation	None-Lg	None-Lg	None-Lg	None-Lg	1	1	1	1
O_SU	Seldom-used units	None-Sm	None-Sm	None-Sm	None-Sm	2	2	2	2
	Quartering vessel								
Q_P&	Propulsion & Generation	Nanuq	CDPF-Lg	CDPF-Lg	CDPF-Lg	9	10	10	10
Q_SU	Seldom-used units	None-Sm	None-Sm	None-Sm	None-Sm	2	2	2	2
	OSR work boats								
O_K	Work boats	None-Sm	None-Sm	None-Sm	None-Sm	2	2	2	2

Assumed Control Device Effectiveness	Restriction	Comment	Reference
Oxidation Catalyst CO reduction efficiency	80%	50-100% of capacity	D.E.C. Marine AB letter, October 9, 2008, and initial stack test
Oxidation Catalyst VOC, HAPs (except metals), Formaldehyde reduction efficiency	70%	50-100% of capacity	D.E.C. Marine AB letter, October 9, 2008
Oxidation Catalyst PM reduction efficiency	50%		D.E.C. Marine AB email, February 9, 2009
CDPF reduction efficiency CO, VOC, HAPs	90%		CleanAIR CDPF guarantee
CDPF reduction efficiency PM	85%		CARB Currently verified, Jan. 2009, CleanAIR Systems PERMIT
Kulluk Generator SCR NOx control	1.6 g/kW-hr	50-100% of capacity	June 2010 Discoverer Stack Testing

Engine Emission Factors / Controls	NOx g/kW-hr	NOx lb/gal	CO lb/MMBtu	CO lb/gal	VOC lb/MMBtu	VOC lb/gal	PM* g/kWhr	PM* lb/gal	
None-Lg	12.00	0.380	0.85	0.115	0.09	0.012	0.50	0.016	1
None-Sm	15.00	0.476	0.95	0.128	0.35	0.047	1.20	0.038	2
heat&boil	20 lb/kgal	0.020	5 lb/kgal	0.005	1 lb/kgal	0.001	3 lb/kgal	0.003	3
Kulluk-SCR	1.60	0.051	-	-	-	-	-	-	4
SCR	1.60	0.051	-	-	-	-	-	-	5
Kulluk-OxyCat	-	-	-	-	-	-	0.200	0.006	6
OxyCat-Lg	-	-	0.170	0.023	0.027	0.004	0.250	0.008	7
OxyCat-Sm	-	-	0.190	0.026	0.105	0.014	0.600	0.019	8
Nanuq	9	0.285	-	-	-	-	-	-	9
CDPF-Lg	-	-	0.085	0.011	0.009	0.001	0.075	0.002	10
Electric	0	0	0	0	0	0	0	0	NA

*PM2.5

References

None-Lg	1	NOx & PM: Recent stack test data, CO & VOC:AP-42 Table 3.4-1 Internal Combustion, Large Stationary Engines (fuel Input)-uncontrolled; ver. 10/1996
None-Sm	2	NOx & PM: Recent stack test data, CO & VOC: AP-42.Table 3.3-1 Internal Combustion, Diesel (fuel input)-uncontrolled; ver. 10/1996
heat&boil	3	NOx & PM: Recent Stack test data, CO & VOC: AP-42. Table 1.11-2 External Combustion, Small Boilers-waste oil; ver 10/1996
Kulluk-SCR	4	Emission factors based on stack tests from the Frontier Discoverer
SCR	5	Selective Catalytic Reduction NOx emission factor based on stack tests
Kulluk-OxyCat	6	PM: Tier 2 engines
OxyCat-Lg	7	Oxidation Catalyst controls applied to reference (1) emission factors
OxyCat-Sm	8	Oxidation Catalyst controls applied to reference (2) emission factors
Nanuq	9	CAT3806 Diesel Engine Technical data sheet
CDPF-Lg	10	Catalytic Diesel Particulate Filters controls applied to reference (1) emission factors

Air Sciences Inc.	PROJECT TITLE: Shell - Exploration Drilling	BY: S. Pryor		
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ENGINEERING CALCULATIONS	SUBJECT: Kulluk / Beaufort Pmt App	DATE: February 27, 2011		

FUEL USE - MAX DAILY

Emission Units to permit:	Capacity Values		Capacity fuel - hourly			Max fuel - daily					
						MLC Case		Drilling Case		Cementing/Logging Case	
			MMBtu/hr	gal/hr		MMBtu	gal	MMBtu	gal	MMBtu	gal
Kulluk											
Generation	8,500	hp	50.58	375		1,214	8,991	1,214	8,991	857	6,347
MLC HPU'S	1,500	hp	10.50	78		252	1,867	0	0	0	0
Air compressors	1,500	hp	10.50	78		252	1,867	0	0	0	0
Cranes	900	hp	2.52	19		18	134	18	134	30	224
Heaters & Boilers	6	MMBtu/hr	6.00	44		144	1,067	144	1,067	144	1,067
Seldom-used units	566	gal/30-days	0.11	0.79	group limit	3	19	3	19	3	19
Emergency Generator	77	gal/30-days	5.198	38.50	group limit	10	77	10	77	10	77
				KULLUK - SUBTOTAL			*14,021*		*10,288*		*7,733*
Primary Ice Management											
Propulsion & Generation	32,200	hp	225	1,670		5,410	40,071	5,410	40,071	5,410	40,071
Heaters & Boilers	10	MMBtu/hr	10	74		240	1,778	240	1,778	240	1,778
Seldom-used units	100	gal/wk	0.080	0.60	group limit	2	14	2	14	2	14
				ICE MANAGEMENT - SUBTOTAL			*41,863*		*41,863*		*41,863*
Secondary Ice Management / Anchor Handler											
Propulsion & Generation	32,200	hp	225	1,670		5,410	40,071	5,410	40,071	5,410	40,071
Heaters & Boilers	10	MMBtu/hr	10	74		240	1,778	240	1,778	240	1,778
Seldom-used units	100	gal/wk	0.080	0.60	group limit	2	14	2	14	2	14
				ANCHOR HANDLER - SUBTOTAL			*41,863*		*41,863*		*41,863*
Resupply Ship - transport mode											
Propulsion & Generation	12,000	hp	84	622		162	1,200	162	1,200	162	1,200
Seldom-used units	20	gal/wk	0.016	0.12	group limit	0.4	2.9	0.4	2.9	0.4	2.9
Resupply Ship - DP mode											
Propulsion & Generation	12,000	hp	84	622		648	4,800	648	4,800	648	4,800
Seldom-used units	20	gal/wk	0.016	0.12	group limit	0.4	2.9	0.4	2.9	0.4	2.9
				RESUPPLY SHIPS - SUBTOTAL			*6,006*		*6,006*		*6,006*
OSR vessel											
Propulsion & Generation	3,487	hp	16	117		378	2,800	378	2,800	378	2,800
Seldom-used units	100	gal/wk	0.080	0.60	group limit	2	14	2	14	2	14
Quartering vessel											
Propulsion & Generation	10,061	hp	27	200		648	4,800	648	4,800	648	4,800
Seldom-used units	100	gal/wk	0.080	0.60	group limit	2	14	2	14	2	14
OSR work boats											
Work boats	3,789	gal/wk	3.05	23		73	541	73	541	73	541
				OSR SHIPS - SUBTOTAL			*8,170*		*8,170*		*8,170*
					Total daily use		**111,923**		**108,190**		**105,635**

TOTAL WASTE INCINERATED

	Capacity Values		MLC Case	Drilling Case	Cementing/Logging case
Incinerators			lbs/day	lbs/day	lbs/day
Kulluk	276	lb/hr	3,312	3,312	3,312
Ice Management	154	lb/hr	3,696	3,696	3,696
Anchor Handler	154	lb/hr	3,696	3,696	3,696
OSR vessel	125	lb/hr	3,000	3,000	3,000
Quartering vessel	125	lb/hr	3,000	3,000	3,000
		total lbs/day	**16,704**	**16,704**	**16,704**

FUEL USE - MAX ANNUAL

Emission Units to permit:	Capacity Values		Capacity fuel - hourly			Max fuel - Annual (Modeling only)						
						MLC Case		Drilling Case		Cementing/Logging Case		Total
			MMBtu/hr	gal/hr		MMBtu	gal	MMBtu	gal	MMBtu	gal	gal
Kulluk												
Generation	8,500	hp	50.58	375		24,276	179,822	58,262	431,573	44,554	330,027	941,422
MLC HPU'S	1,500	hp	10.50	78		5,040	37,333	0	0	0	0	37,333
Air compressors	1,500	hp	10.50	78		5,040	37,333	0	0	0	0	37,333
Cranes	900	hp	2.52	19		363	2,688	871	6,451	1,572	11,648	20,787
Heaters & Boilers	6	MMBtu/hr	6.00	44		2,880	21,333	6,912	51,200	7,488	55,467	128,000
Seldom-used units	566	gal/30-days	0.11	0.79	group limit	51	377	122	906	132	981	2,264
Emergency Generator	77	gal/30-days	5.198	38.50	group limit	7	51	17	123	18	133	308
				KULLUK - SUBTOTAL			*278,939*		*490,253*		*398,256*	*1,167,448*
Primary Ice Management												
Propulsion & Generation	32,200	hp	225	1670		41,113	304,540	98,671	730,897	106,894	791,805	1,827,243
Heaters & Boilers	10	MMBtu/hr	10	74		1,824	13,511	4,378	32,427	4,742	35,129	81,067
Seldom-used units	100	gal/wk	0.080	0.60	group limit	15	109	35	261	38	282	651
				ICE MANAGEMENT - SUBTOTAL			*318,160*		*763,584*		*827,216*	*1,908,961*
Secondary Ice Management / Anchor Handler												
Propulsion & Generation	32,200	hp	225	1670		41,113	304,540	98,671	730,897	106,894	791,805	1,827,243
Heaters & Boilers	10	MMBtu/hr	10	74		1,824	13,511	4,378	32,427	4,742	35,129	81,067
Seldom-used units	100	gal/wk	0.080	0.595	group limit	15	109	35	261	38	282	651
				ANCHOR HANDLER - SUBTOTAL			*318,160*		*763,584*		*827,216*	*1,908,961*
Resupply Ship - transport mode												
Propulsion & Generation	12,000	hp	84	622		1,296	9,600	3,110	23,040	3,370	24,960	57,600
Seldom-used units	20	gal/wk	0.016	0.12	group limit	8	57	19	137	20	149	343
Resupply Ship - DP mode												
Propulsion & Generation	12,000	hp	84	622		2,592	19,200	6,221	46,080	6,739	49,920	115,200
Seldom-used units	20	gal/wk	0.016	0.12	group limit	8	57	19	137	20	149	343
				RESUPPLY SHIPS - SUBTOTAL			*28,914*		*69,394*		*75,177*	*173,486*
OSR vessel												
Propulsion & Generation	3,487	hp	16	117		4,536	33,600	10,886	80,640	11,794	87,360	201,600
Seldom-used units	100	gal/wk	0.080	0.6	group limit	39	286	93	686	100	743	1,714
Quartering vessel												
Propulsion & Generation	10,061	hp	27	200		7,776	57,600	18,662	138,240	20,218	149,760	345,600
Seldom-used units	100	gal/wk	0.080	0.6	group limit	39	286	93	686	100	743	1,714
OSR work boats												
Work boats	3,789	gal/wk	3.05	23		1,462	10,827	3,508	25,984	3,800	28,149	64,960
				OSR SHIPS - SUBTOTAL			*102,598*		*246,235*		*266,755*	*615,589*
				Total Annual Use			**1,046,772**		**2,333,052**		**2,394,621**	**5,774,444**
				TOTAL ANNUAL GALLONS				5,774,444				

TOTAL WASTE INCINERATED

	Capacity Values			MLC Case	Drilling Case	Cementing/Logging case	Total
Incinerators				lbs/year	lbs/year	lbs/year	tons /year
Kulluk	276	lb/hr		66,240	158,976	172,224	199
Ice Management	154	lb/hr		28,090	67,415	73,033	84
Anchor Handler	154	lb/hr		28,090	67,415	73,033	84
OSR vessel	125	lb/hr		60,000	144,000	156,000	180
Quartering vessel	125	lb/hr		60,000	144,000	156,000	180
			total lbs/yr	**242,419**	**581,806**	**630,290**	**727**

*This activity cannot occur simultaneously with Resupply - DP mode. DP mode has greater impacts.

NOx EMISSIONS - FOR IMPACT MODELING

shading represents requested limit to be demonstrated by documentation of daily fuel consumption

shading represents requested limit to be demonstrated by documentation of weekly fuel consumption

Source	Emission Factor	unit	*lb/hr^*	lb/hr	Max *lb/day^*	MLC lb/day	DRILL lb/day	C/L lb/day	TOTAL ton/year
				NOx_pph	Max_NOx_ppd	MLC_NOx_ppd	Drill_NOx_ppd	C/L_NOx_ppd	NOx_tpy
Kulluk									
Generation	0.051	lb/gal		19.00	456	456	456	322	24
MLC HPU'S	0.476	lb/gal		36.99	888	888	0	0	9
Air compressors	0.380	lb/gal		29.59	710	710	0	0	7
Cranes	0.476	lb/gal		8.88	107	64	64	107	5
Heaters & Boilers	0.020	lb/gal		0.89	21	21	21	21	1
Seldom-used units	0.476	lb/gal		0.37	8.97	8.97	8.97	8.97	0.54
Emergency Generator	0.476	lb/gal		18.31	36.62	36.62	36.62	36.62	0.07
Primary Ice Management									
Propulsion & Generation	0.051	lb/gal		85	2,033	2,033	2,033	2,033	46
Heaters & Boilers	0.020	lb/gal		1.48	36	36	36	36	0.81
Seldom-used units	0.476	lb/gal		0.28	6.79	6.79	6.79	6.79	0.15
Secondary Ice Management / Anchor Handler									
Propulsion & Generation	0.051	lb/gal		85	2,033	2,033	2,033	2,033	46
Heaters & Boilers	0.020	lb/gal		1.48	36	36	36	36	0.81
Seldom-used units	0.476	lb/gal		0.28	6.79	6.79	6.79	6.79	0.15
Resupply Ship - transport mode									
Propulsion & Generation	0.380	lb/gal	*237*	(0*)	457	(0*)	(0*)	(0*)	11
Seldom-used units	0.476	lb/gal	*0.057*	(0*)	1.36	(0*)	(0*)	(0*)	0.08
Resupply Ship - DP mode									
Propulsion & Generation	0.380	lb/gal		237	1,826	1,826	1,826	1,826	22
Seldom-used units	0.476	lb/gal		0.06	1.36	1.36	1.36	1.36	0.08
OSR vessel									
Propulsion & Generation	0.380	lb/gal		44	1,065	1,065	1,065	1,065	38
Seldom-used units	0.476	lb/gal		0.28	6.79	6.79	6.79	6.79	0.41
Quartering vessel									
Propulsion & Generation	0.285	lb/gal		57	1,370	1,370	1,370	1,370	49
Seldom-used units	0.476	lb/gal		0.28	6.79	6.79	6.79	6.79	0.41
OSR work boats									
Work boats	0.476	lb/gal		11	257	257	257	257	15
TOTAL				**637**	**11,369**	**10,869**	**9,271**	**9,179**	**278**

NOx EMISSIONS

Source	Emission Factor	unit	NO_X lb/hr	NO_X lb/day	NO_X ton/year
			I_NOx_pph	I_NOx_ppd	I_NOx_tpy
Incinerators					
Kulluk	3	lb/ton	0.41	4.97	0.30
Ice Management	3	lb/ton	0.23	5.54	0.13
Anchor Handler	3	lb/ton	0.23	5.54	0.13
OSR vessel	3	lb/ton	0.19	4.50	0.27
Quartering vessel	3	lb/ton	0.19	4.50	0.27
			1.25	**25.06**	**1.09**

Source	pollutant	EF	unit	reference
Incinerators	NO_X	3	lb/ton	AP42 Table 2.1-12, 10/96

*This activity cannot occur simultaneously with Resupply - DP mode. DP mode has greater impacts.

^Values in this column represent maximum emissions independent of activity.

$PM_{2.5}$ EMISSIONS - FOR IMPACT MODELING

shading represents requested limit to be demonstrated by documentation of daily fuel consumption

shading represents requested limit to be demonstrated by documentation of weekly fuel consumption

Source	Emission Factor	unit	*lb/hr^*	lb/hr	Max *lb/day^*	MLC lb/day	DRILL lb/day	C/L lb/day	TOTAL ton/year
Kulluk									
Generation	0.008	lb/gal		2.97	71	71	71	50	3.73
MLC HPU'S	0.019	lb/gal		1.48	36	36	0	0	0.36
Air compressors	0.008	lb/gal		0.62	15	15	0	0	0.15
Cranes	0.019	lb/gal		0.36	4	3	3	4	0.20
Heaters & Boilers	0.003	lb/gal		0.15	4	4	4	4	0.21
Seldom-used units	0.038	lb/gal		0.03	0.72	0.72	0.72	0.72	0.04
Emergency Generator	0.038	lb/gal		1.46	2.93	2.93	2.93	2.93	0.01
Primary Ice Management									
Propulsion & Generation	0.008	lb/gal		13	318	318	318	318	7
Heaters & Boilers	0.003	lb/gal		0.24	6	6	6	6	0.13
Seldom-used units	0.038	lb/gal		0.02	0.54	0.54	0.54	0.54	0.01
Secondary Ice Management / Anchor Handler									
Propulsion & Generation	0.008	lb/gal		13	318	318	318	318	7
Heaters & Boilers	0.003	lb/gal		0.24	6	6	6	6	0.13
Seldom-used units	0.038	lb/gal		0.02	0.54	0.54	0.54	0.54	0.01
Resupply Ship - transport mode									
Propulsion & Generation	0.016	lb/gal	*10*	(0*)	19	(0*)	(0*)	(0*)	0.46
Seldom-used units	0.038	lb/gal	*0.005*	(0*)	0.11	(0*)	(0*)	(0*)	0.01
Resupply Ship - DP mode									
Propulsion & Generation	0.016	lb/gal		10	76	76	76	76	1
Seldom-used units	0.038	lb/gal		0.00	0.11	0.11	0.11	0.11	0.01
OSR vessel									
Propulsion & Generation	0.016	lb/gal		2	44	44	44	44	2
Seldom-used units	0.038	lb/gal		0.02	0.54	0.54	0.54	0.54	0.03
Quartering vessel									
Propulsion & Generation	0.002	lb/gal		0	11	11	11	11	0
Seldom-used units	0.038	lb/gal		0.02	0.54	0.54	0.54	0.54	0.03
OSR work boats									
Work boats	0.038	lb/gal		0.86	21	21	21	21	1
TOTAL				**47**	**954**	**933**	**883**	**863**	**24**

PM_{10} & $PM_{2.5}$ EMISSIONS

Source	Emission Factor PM_{10}	Emission Factor $PM_{2.5}$	unit	PM_{10} lb/hr	$PM_{2.5}$ lb/hr	PM_{10} lb/day	$PM_{2.5}$ lb/day	PM_{10} ton/year	$PM_{2.5}$ ton/year
Incinerators									
Kulluk	16.4	14	lb/ton	2.26	1.93	27.16	23.18	1.63	1.39
Ice Management	16.4	14	lb/ton	1.26	1.08	30.31	25.87	0.69	0.59
Anchor Handler	16.4	14	lb/ton	1.26	1.08	30.31	25.87	0.69	0.59
OSR vessel	16.4	14	lb/ton	1.03	0.88	24.60	21.00	1.48	1.26
Quartering vessel	16.4	14	lb/ton	1.03	0.88	24.60	21.00	1.48	1.26
				6.84	**5.84**	**136.97**	**116.93**	**5.96**	**5.09**

Source	pollutant	EF	unit	reference
Incinerators	PM_{10}	16.4	lb/ton	Disco Stack Test June 2010 (multiplied by a safety factor of 2)
	$PM_{2.5}$	14	lb/ton	Disco Stack Test June 2010 (multiplied by a safety factor of 2)

*This activity cannot occur simultaneously with Resupply - DP mode. DP mode has greater impacts.

^Values in this column represent maximum emissions independent of activity.

Air Sciences Inc.	PROJECT TITLE: Shell - Exploration Drilling		BY: S. Pryor	
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CO EMISSIONS - FOR IMPACT MODELING

				CO_pph	Max_CO_ppd	MLC_CO_ppd	Drill_CO_ppd	C/L_CO_ppd	CO_tpy
					Max	MLC	DRILL	C/L	TOTAL
Source	Emission Factor	unit	*lb/hr^*	lb/hr	*lb/day^*	lb/day	lb/day	lb/day	ton/year
Kulluk									
Generation	0.023	lb/gal		8.60	206	206	206	146	10.80
MLC HPU'S	0.026	lb/gal		2.00	48	48	0	0	0.48
Air compressors	0.023	lb/gal		1.79	43	43	0	0	0.43
Cranes	0.026	lb/gal		0.48	6	3	3	6	0.27
Heaters & Boilers	0.005	lb/gal		0.22	5	5	5	5	0.32
Seldom-used units	0.128	lb/gal		0.10	2.42	2.42	2.42	2.42	0.15
Emergency Generator	0.128	lb/gal		4.94	9.88	9.88	9.88	9.88	0.02
Primary Ice Management									
Propulsion & Generation	0.023	lb/gal		38.32	920	920	920	920	21
Heaters & Boilers	0.005	lb/gal		0.37	9	9	9	9	0.20
Seldom-used units	0.128	lb/gal		0.08	1.83	1.83	1.83	1.83	0.04
Secondary Ice Management / Anchor Handler									
Propulsion & Generation	0.023	lb/gal		38.32	920	920	920	920	21
Heaters & Boilers	0.005	lb/gal		0.37	9	9	9	9	0.20
Seldom-used units	0.128	lb/gal		0.08	1.83	1.83	1.83	1.83	0.04
Resupply Ship - transport mode									
Propulsion & Generation	0.115	lb/gal	*71*	(0*)	138	(0*)	(0*)	(0*)	3.30
Seldom-used units	0.128	lb/gal	*0.015*	(0*)	0.37	(0*)	(0*)	(0*)	0.02
Resupply Ship - DP mode									
Propulsion & Generation	0.115	lb/gal		71	551	551	551	551	7
Seldom-used units	0.128	lb/gal		0.02	0.37	0.37	0.37	0.37	0.02
OSR vessel									
Propulsion & Generation	0.115	lb/gal		13	321	321	321	321	12
Seldom-used units	0.128	lb/gal		0.08	1.83	1.83	1.83	1.83	0.11
Quartering vessel									
Propulsion & Generation	0.011	lb/gal		2	55	55	55	55	2
Seldom-used units	0.128	lb/gal		0.08	1.83	1.83	1.83	1.83	0.11
OSR work boats									
Work boats	0.128	lb/gal		3	69	69	69	69	4
TOTAL				**186**	**3,320**	**3,179**	**3,089**	**3,030**	**83**

CO EMISSIONS

			I_CO_pph	I_CO_ppd	I_CO_tpy
			CO	CO	CO
Source	Emission Factor	unit	lb/hr	lb/day	ton/year
Incinerators					
Kulluk	300	lb/ton	41.40	496.80	29.81
Ice Management	300	lb/ton	23.10	554.40	12.64
Anchor Handler	300	lb/ton	23.10	554.40	12.64
OSR vessel	300	lb/ton	18.75	450.00	27.00
Quartering vessel	300	lb/ton	18.75	450.00	27.00
			125.10	**2,505.60**	**109.09**

Source	pollutant	EF	unit	reference
Incinerators	CO	300	lb/ton	AP42 Table 2.1-12, 10/96

*This activity cannot occur simultaneously with Resupply - DP mode. DP mode has greater impacts.

^Values in this column represent maximum emissions independent of activity.

SO_2 EMISSIONS - FOR IMPACT MODELING

				SO2_pph	Max_SO2_ppd	MLC_SO2_ppd	Drill_SO2_ppd	C/L_SO2_ppd	SO2_tpy
					Max	MLC	DRILL	C/L	TOTAL
Source	Emission Factor	unit	*lb/hr^*	lb/hr	*lb/day^*	lb/day	lb/day	lb/day	ton/year
Kulluk									
Generation	0.001419	lb/gal		0.53	12.75	12.75	12.75	9.00	0.67
MLC HPU'S	0.001419	lb/gal		0.11	2.65	2.65	0	0	0.03
Air compressors	0.001419	lb/gal		0.11	2.65	2.65	0	0	0.03
Cranes	0.001419	lb/gal		0.03	0.32	0.19	0.19	0.32	0.01
Heaters & Boilers	0.001419	lb/gal		0.06	1.51	1.51	1.51	1.51	0.09
Seldom-used units	0.001419	lb/gal		0.0011	0.0268	0.0268	0.0268	0.0268	0.0016
Emergency Generator	0.001419	lb/gal		0.0546	0.1092	0.1092	0.1092	0.1092	0.0002
Primary Ice Management									
Propulsion & Generation	0.001419	lb/gal		2.37	56.84	56.84	56.84	56.84	1.30
Heaters & Boilers	0.001419	lb/gal		0.11	2.52	2.52	2.52	2.52	0.06
Seldom-used units	0.001419	lb/gal		0.0008	0.0203	0.0203	0.0203	0.0203	0.0005
Secondary Ice Management / Anchor Handler									
Propulsion & Generation	0.001419	lb/gal		2.37	56.84	56.84	56.84	56.84	1.30
Heaters & Boilers	0.001419	lb/gal		0.11	2.52	2.52	2.52	2.52	0.06
Seldom-used units	0.001419	lb/gal		0.0008	0.0203	0.0203	0.0203	0.0203	0.0005
Resupply Ship - transport mode									
Propulsion & Generation	0.001419	lb/gal	*0.88*	(0*)	1.70	(0*)	(0*)	(0*)	0.04
Seldom-used units	0.001419	lb/gal	*0.000*	(0*)	0.00	(0*)	(0*)	(0*)	0.00
Resupply Ship - DP mode									
Propulsion & Generation	0.001419	lb/gal		0.88	6.81	6.81	6.81	6.81	0.08
Seldom-used units	0.001419	lb/gal		0.0002	0.0041	0.0041	0.0041	0.0041	0.0002
OSR vessel									
Propulsion & Generation	0.001419	lb/gal		0.17	3.97	3.97	3.97	3.97	0.14
Seldom-used units	0.001419	lb/gal		0.0008	0.0203	0.0203	0.0203	0.0203	0.0012
Quartering vessel									
Propulsion & Generation	0.001419	lb/gal		0.28	6.81	6.81	6.81	6.81	0.25
Seldom-used units	0.001419	lb/gal		0.0008	0.0203	0.0203	0.0203	0.0203	0.0012
OSR work boats									
Work boats	0.001419	lb/gal		0.03	0.77	0.77	0.77	0.77	0.05
TOTAL				**7**	**159**	**157**	**152**	**148**	**4**

SO2 EMISSIONS

			I_SO2_pph	I_SO2_ppd	I_SO2_tpy
			SO_2	SO_2	SO_2
Source	Emission Factor	unit	lb/hr	lb/day	ton/year
Incinerators					
Kulluk	2.5	lb/ton	0.35	4.14	0.25
Ice Management	2.5	lb/ton	0.19	4.62	0.11
Anchor Handler	2.5	lb/ton	0.19	4.62	0.11
OSR vessel	2.5	lb/ton	0.16	3.75	0.23
Quartering vessel	2.5	lb/ton	0.16	3.75	0.23
			1.04	**20.88**	**0.91**

Source	pollutant	EF	unit	reference
Incinerators	SO_2	2.5	lb/ton	AP42 Table 2.1-12, 10/96

S = the weight % Sulfur in the Fuel | 0.0100% | 0.0105 lb/MMBtu

*This activity cannot occur simultaneously with Resupply - DP mode. DP mode has greater impacts.

^Values in this column represent maximum emissions independent of activity.

Air Sciences Inc.	PROJECT TITLE: Shell - Exploration Drilling		BY: S. Pryor	
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ENGINEERING CALCULATIONS	SUBJECT: Kulluk / Beaufort Pmt App		DATE: February 27, 2011	

VOC EMISSIONS - FOR IMPACT MODELING

				VOC_pph	Max_VOC_ppd	MLC_VOC_ppd	Drill_VOC_ppd	C/L_VOC_ppd	VOC_tpy
					Max	MLC	DRILL	C/L	TOTAL
Source	Emission Factor	unit	*lb/hr^*	lb/hr	*lb/day^*	lb/day	lb/day	lb/day	ton/year
Kulluk									
Generation	0.004	lb/gal		1.37	32.77	32.77	32.77	23.13	1.72
MLC HPU'S	0.014	lb/gal		1.10	26.46	26.46	0	0	0.26
Air compressors	0.004	lb/gal		0.28	6.80	6.80	0	0	0.07
Cranes	0.014	lb/gal		0.26	3.18	1.91	1.91	3.18	0.15
Heaters & Boilers	0.001	lb/gal		0.04	1.07	1.07	1.07	1.07	0.06
Seldom-used units	0.047	lb/gal		0.04	0.89	0.89	0.89	0.89	0.05
Emergency Generator	0.047	lb/gal		1.82	3.64	3.64	3.64	3.64	0.01
Primary Ice Management									
Propulsion & Generation	0.004	lb/gal		6.09	146.06	146.06	146.06	146.06	3.33
Heaters & Boilers	0.001	lb/gal		0.07	1.78	1.78	1.78	1.78	0.04
Seldom-used units	0.047	lb/gal		0.03	0.68	0.68	0.68	0.68	0.02
Secondary Ice Management / Anchor Handler									
Propulsion & Generation	0.004	lb/gal		6.09	146.06	146.06	146.06	146.06	3.33
Heaters & Boilers	0.001	lb/gal		0.07	1.78	1.78	1.78	1.78	0.04
Seldom-used units	0.047	lb/gal		0.03	0.68	0.68	0.68	0.68	0.02
Resupply Ship - transport mode									
Propulsion & Generation	0.012	lb/gal	*7.56*	(0*)	14.58	(0*)	(0*)	(0*)	0.35
Seldom-used units	0.047	lb/gal	*0.006*	(0*)	0.14	(0*)	(0*)	(0*)	0.01
Resupply Ship - DP mode									
Propulsion & Generation	0.012	lb/gal		7.56	58.32	58.32	58.32	58.32	0.70
Seldom-used units	0.047	lb/gal		0.0056	0.1350	0.1350	0.1350	0.1350	0.0081
OSR vessel									
Propulsion & Generation	0.012	lb/gal		1.42	34.02	34.02	34.02	34.02	1.22
Seldom-used units	0.047	lb/gal		0.03	0.68	0.68	0.68	0.68	0.04
Quartering vessel									
Propulsion & Generation	0.001	lb/gal		0.24	5.83	5.83	5.83	5.83	0.21
Seldom-used units	0.047	lb/gal		0.03	0.68	0.68	0.68	0.68	0.04
OSR work boats									
Work boats	0.047	lb/gal		1.07	25.58	25.58	25.58	25.58	1.53
TOTAL				**28**	**512**	**496**	**463**	**454**	**13**

VOC EMISSIONS

			I_VOC_pph	I_VOC_ppd	I_VOC_tpy
			VOC	VOC	VOC
Source	Emission Factor	unit	lb/hr	lb/day	ton/year
Incinerators					
Kulluk	100	lb/ton	13.80	165.60	9.94
Ice Management	100	lb/ton	7.70	184.80	4.21
Anchor Handler	100	lb/ton	7.70	184.80	4.21
OSR vessel	100	lb/ton	6.25	150.00	9.00
Quartering vessel	100	lb/ton	6.25	150.00	9.00
			41.70	**835.20**	**36.36**

Source	pollutant	EF	unit	reference
Incinerators	VOC	100	lb/ton	AP42 Table 2.1-12, 10/96

*This activity cannot occur simultaneously with Resupply - DP mode. DP mode has greater impacts.

^Values in this column represent maximum emissions independent of activity.

LEAD EMISSIONS

Source	Emission Factor	unit	lb/hr^	Lead_pph lb/hr	Max_Lead_ppd Max lb/day^	MLC_Lead_ppd MLC lb/day	Drill_Lead_ppd DRILL lb/day	C/L_Lead_ppd C/L lb/day	Lead_tpy TOTAL ton/year
Kulluk									
Generation	3.92E-06	lb/gal		1.47E-03	3.52E-02	3.52E-02	3.52E-02	2.48E-02	1.84E-03
MLC HPU'S	3.92E-06	lb/gal		3.05E-04	7.31E-03	7.31E-03	0.00E+00	0.00E+00	7.31E-05
Air compressors	3.92E-06	lb/gal		3.05E-04	7.31E-03	7.31E-03	0.00E+00	0.00E+00	7.31E-05
Cranes	3.92E-06	lb/gal		7.31E-05	8.77E-04	5.26E-04	5.26E-04	8.77E-04	4.07E-05
Heaters & Boilers	1.22E-06	lb/gal		5.40E-05	1.30E-03	1.30E-03	1.30E-03	1.30E-03	7.78E-05
Seldom-used units	3.92E-06	lb/gal		3.08E-06	7.39E-05	7.39E-05	7.39E-05	7.39E-05	4.43E-06
Emergency Generator	3.92E-06	lb/gal		1.51E-04	3.01E-04	3.01E-04	3.01E-04	3.01E-04	6.03E-07
Primary Ice Management									
Propulsion & Generation	3.92E-06	lb/gal		6.54E-03	1.57E-01	1.57E-01	1.57E-01	1.57E-01	3.58E-03
Heaters & Boilers	1.22E-06	lb/gal		9.00E-05	2.16E-03	2.16E-03	2.16E-03	2.16E-03	4.92E-05
Seldom-used units	3.92E-06	lb/gal		2.33E-06	5.59E-05	5.59E-05	5.59E-05	5.59E-05	1.28E-06
Secondary Ice Management / Anchor Handler									
Propulsion & Generation	3.92E-06	lb/gal		6.54E-03	1.57E-01	1.57E-01	1.57E-01	1.57E-01	3.58E-03
Heaters & Boilers	1.22E-06	lb/gal		9.00E-05	2.16E-03	2.16E-03	2.16E-03	2.16E-03	4.92E-05
Seldom-used units	3.92E-06	lb/gal		2.33E-06	5.59E-05	5.59E-05	5.59E-05	5.59E-05	1.28E-06
Resupply Ship - transport mode									
Propulsion & Generation	3.92E-06	lb/gal	*2.44E-03*	(0*)	4.70E-03	(0*)	(0*)	(0*)	1.13E-04
Seldom-used units	3.92E-06	lb/gal	*4.66E-07*	(0*)	1.12E-05	(0*)	(0*)	(0*)	6.71E-07
Resupply Ship - DP mode									
Propulsion & Generation	3.92E-06	lb/gal		2.44E-03	1.88E-02	1.88E-02	1.88E-02	1.88E-02	2.26E-04
Seldom-used units	3.92E-06	lb/gal		4.66E-07	1.12E-05	1.12E-05	1.12E-05	1.12E-05	6.71E-07
OSR vessel									
Propulsion & Generation	3.92E-06	lb/gal		4.57E-04	1.10E-02	1.10E-02	1.10E-02	1.10E-02	3.95E-04
Seldom-used units	3.92E-06	lb/gal		2.33E-06	5.59E-05	5.59E-05	5.59E-05	5.59E-05	3.36E-06
Quartering vessel									
Propulsion & Generation	3.92E-06	lb/gal		7.83E-04	1.88E-02	1.88E-02	1.88E-02	1.88E-02	6.77E-04
Seldom-used units	3.92E-06	lb/gal		2.33E-06	5.59E-05	5.59E-05	5.59E-05	5.59E-05	3.36E-06
OSR work boats									
Work boats	3.92E-06	lb/gal		8.83E-05	2.12E-03	2.12E-03	2.12E-03	2.12E-03	1.27E-04
TOTAL				**1.94E-02**	**4.26E-01**	**4.21E-01**	**4.06E-01**	**3.96E-01**	**1.09E-02**

LEAD EMISSIONS

Source	Emission Factor	unit	I_Lead_pph Lead lb/hr	I_Lead_ppd Lead lb/day	I_Lead_tpy Lead ton/year
Incinerators					
Kulluk	0.213	lb/ton	0.03	0.35	0.02
Ice Management	0.213	lb/ton	0.02	0.39	0.01
Anchor Handler	0.213	lb/ton	0.02	0.39	0.01
OSR vessel	0.213	lb/ton	0.01	0.32	0.02
Quartering vessel	0.213	lb/ton	0.01	0.32	0.02
			0.09	**1.78**	**0.08**

Source	pollutant	EF	unit	EF	unit
IC Engines	Lead	2.90E-05	lb/MMBtu	3.92E-06	lb/gal
Boilers	Lead	9	lb/10^{12} Btu	1.22E-06	lb/gal
Incinerators	Lead			0.213	lb/ton

Reference	
IC Engines	L & E Air Emissions from Sources of Lead and Lead Compounds, EPA 454/R-98-006, May 1998, Section 5.2.2, Distillate oil-fired gas turbines
Boilers	AP42, Table 1.3-10. Emission Factors For Trace Elements From Distillate Fuel Oil Combustion Sources
Incinerators	AP42, Table 2.2-2 - Metals Emission Factors for Mass Burn and Modular Excess Air Combustors

*This activity cannot occur simultaneously with Resupply - DP mode. DP mode has greater impacts.

^Values in this column represent maximum emissions independent of activity.

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HAP EMISSIONS

Source	Emission Factor	unit	Control	*lb/hr^*	lb/hr	Max *lb/day^*	MLC lb/day	DRILL lb/day	C/L lb/day	TOTAL ton/year
Kulluk										
Generation	1.65E-04	lb/gal	SCR, OxyCat		6.16E-02	1.48E+00	1.48E+00	1.48E+00	1.04E+00	7.75E-02
MLC HPU'S	1.65E-04	lb/gal	OxyCat		1.28E-02	3.07E-01	3.07E-01	0.00E+00	0.00E+00	3.07E-03
Air compressors	1.65E-04	lb/gal	OxyCat		1.28E-02	3.07E-01	3.07E-01	0.00E+00	0.00E+00	3.07E-03
Cranes	1.65E-04	lb/gal	OxyCat		3.07E-03	3.69E-02	2.21E-02	2.21E-02	3.69E-02	1.71E-03
Heaters & Boilers	4.42E-05	lb/gal			1.96E-03	4.71E-02	4.71E-02	4.71E-02	4.71E-02	2.83E-03
Seldom-used units	5.31E-04	lb/gal			4.17E-04	1.00E-02	1.00E-02	1.00E-02	1.00E-02	6.01E-04
Emergency Generator	5.31E-04	lb/gal			2.04E-02	4.09E-02	4.09E-02	4.09E-02	4.09E-02	8.17E-05
Primary Ice Management										
Propulsion & Generation	1.65E-04	lb/gal	SCR, OxyCat		2.75E-01	6.59E+00	6.59E+00	6.59E+00	6.59E+00	1.50E-01
Heaters & Boilers	4.42E-05	lb/gal			3.27E-03	7.85E-02	7.85E-02	7.85E-02	7.85E-02	1.79E-03
Seldom-used units	5.31E-04	lb/gal			3.16E-04	7.58E-03	7.58E-03	7.58E-03	7.58E-03	1.73E-04
Secondary Ice Management / Anchor Handler										
Propulsion & Generation	1.65E-04	lb/gal	SCR, OxyCat		2.75E-01	6.59E+00	6.59E+00	6.59E+00	6.59E+00	1.50E-01
Heaters & Boilers	4.42E-05	lb/gal			3.27E-03	7.85E-02	7.85E-02	7.85E-02	7.85E-02	1.79E-03
Seldom-used units	5.31E-04	lb/gal			3.16E-04	7.58E-03	7.58E-03	7.58E-03	7.58E-03	1.73E-04
Resupply Ship - transport mode										
Propulsion & Generation	5.31E-04	lb/gal		*3.30E-01*	(0*)	6.37E-01	(0*)	(0*)	(0*)	1.53E-02
Seldom-used units	5.31E-04	lb/gal		*6.32E-05*	(0*)	1.52E-03	(0*)	(0*)	(0*)	9.10E-05
Resupply Ship - DP mode										
Propulsion & Generation	5.31E-04	lb/gal			3.30E-01	2.55E+00	2.55E+00	2.55E+00	2.55E+00	3.06E-02
Seldom-used units	5.31E-04	lb/gal			6.32E-05	1.52E-03	1.52E-03	1.52E-03	1.52E-03	9.10E-05
OSR vessel										
Propulsion & Generation	5.31E-04	lb/gal			6.19E-02	1.49E+00	1.49E+00	1.49E+00	1.49E+00	5.35E-02
Seldom-used units	5.31E-04	lb/gal			3.16E-04	7.58E-03	7.58E-03	7.58E-03	7.58E-03	4.55E-04
Quartering vessel										
Propulsion & Generation	5.31E-04	lb/gal	CDPF		1.06E-01	2.55E+00	2.55E+00	2.55E+00	2.55E+00	9.17E-02
Seldom-used units	5.31E-04	lb/gal			3.16E-04	7.58E-03	7.58E-03	7.58E-03	7.58E-03	4.55E-04
OSR work boats										
Work boats	5.31E-04	lb/gal			1.20E-02	2.87E-01	2.87E-01	2.87E-01	2.87E-01	1.72E-02
TOTAL					**1.18**	**23.11**	**22.46**	**21.84**	**21.42**	**0.60**

HAP EMISSIONS

Source	Emission Factor	unit	HAP lb/hr	HAP lb/day	HAP ton/year
Incinerators					
Kulluk	2.51E-01	lb/ton	0.03	0.42	0.02
Ice Management	2.51E-01	lb/ton	0.02	0.46	0.01
Anchor Handler	2.51E-01	lb/ton	0.02	0.46	0.01
OSR vessel	2.51E-01	lb/ton	0.02	0.38	0.02
Quartering vessel	2.51E-01	lb/ton	0.02	0.38	0.02
			0.10	**2.09**	**0.09**

Source	pollutant	EF	unit
IC Engines-uncontrolled	HAP	5.31E-04	lb/gal
IC Engines-OxyCat controlled	HAP	1.65E-04	lb/gal
Boilers	HAP	4.42E-05	lb/gal
Incinerators	HAP	2.51E-01	lb/ton

*This activity cannot occur simultaneously with Resupply - DP mode. DP mode has greater impacts.

^Values in this column represent maximum emissions independent of activity.

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FORMALDEHYDE EMISSIONS

Source	Emission Factor	unit	Control	*lb/hr^*	lb/hr	Max *lb/day^*	MLC lb/day	DRILL lb/day	C/L lb/day	TOTAL ton/year
					CH2O_pph	Max_CH2O_ppd	MLC_CH2O_ppd	Drill_CH2O_ppc	C/L_CH2O_ppd	CH2O_tpy
Kulluk										
Generation	4.78E-05	lb/gal	SCR, OxyCat		1.79E-02	4.30E-01	4.30E-01	4.30E-01	3.03E-01	2.25E-02
MLC HPU'S	4.78E-05	lb/gal	OxyCat		3.72E-03	8.92E-02	8.92E-02	0.00E+00	0.00E+00	8.92E-04
Air compressors	4.78E-05	lb/gal	OxyCat		3.72E-03	8.92E-02	8.92E-02	0.00E+00	0.00E+00	8.92E-04
Cranes	4.78E-05	lb/gal	OxyCat		8.92E-04	1.07E-02	6.42E-03	6.42E-03	1.07E-02	4.97E-04
Heaters & Boilers	3.30E-05	lb/gal			1.47E-03	3.52E-02	3.52E-02	3.52E-02	3.52E-02	2.11E-03
Seldom-used units	1.59E-04	lb/gal			1.25E-04	3.01E-03	3.01E-03	3.01E-03	3.01E-03	1.80E-04
Emergency Generator	1.59E-04	lb/gal			6.13E-03	1.23E-02	1.23E-02	1.23E-02	1.23E-02	2.45E-05
Primary Ice Management										
Propulsion & Generation	4.78E-05	lb/gal	SCR, OxyCat		7.98E-02	1.91E+00	1.91E+00	1.91E+00	1.91E+00	4.37E-02
Heaters & Boilers	3.30E-05	lb/gal			2.44E-03	5.87E-02	5.87E-02	5.87E-02	5.87E-02	1.34E-03
Seldom-used units	1.59E-04	lb/gal			9.48E-05	2.28E-03	2.28E-03	2.28E-03	2.28E-03	5.19E-05
Secondary Ice Management / Anchor Handler										
Propulsion & Generation	4.78E-05	lb/gal	SCR, OxyCat		7.98E-02	1.91E+00	1.91E+00	1.91E+00	1.91E+00	4.37E-02
Heaters & Boilers	3.30E-05	lb/gal			2.44E-03	5.87E-02	5.87E-02	5.87E-02	5.87E-02	1.34E-03
Seldom-used units	1.59E-04	lb/gal			9.48E-05	2.28E-03	2.28E-03	2.28E-03	2.28E-03	5.19E-05
Resupply Ship - transport mode										
Propulsion & Generation	1.59E-04	lb/gal		*9.91E-02*	(0*)	1.91E-01	(0*)	(0*)	(0*)	4.59E-03
Seldom-used units	1.59E-04	lb/gal		*1.90E-05*	(0*)	4.55E-04	(0*)	(0*)	(0*)	2.73E-05
Resupply Ship - DP mode										
Propulsion & Generation	1.59E-04	lb/gal			9.91E-02	7.65E-01	7.65E-01	7.65E-01	7.65E-01	9.18E-03
Seldom-used units	1.59E-04	lb/gal			1.90E-05	4.55E-04	4.55E-04	4.55E-04	4.55E-04	2.73E-05
OSR vessel										
Propulsion & Generation	1.59E-04	lb/gal			1.86E-02	4.46E-01	4.46E-01	4.46E-01	4.46E-01	1.61E-02
Seldom-used units	1.59E-04	lb/gal			9.48E-05	2.28E-03	2.28E-03	2.28E-03	2.28E-03	1.37E-04
Quartering vessel										
Propulsion & Generation	1.59E-04	lb/gal	CDPF		3.19E-02	7.65E-01	7.65E-01	7.65E-01	7.65E-01	2.75E-02
Seldom-used units	1.59E-04	lb/gal			9.48E-05	2.28E-03	2.28E-03	2.28E-03	2.28E-03	1.37E-04
OSR work boats										
Work boats	1.59E-04	lb/gal			3.59E-03	8.62E-02	8.62E-02	8.62E-02	8.62E-02	5.17E-03
TOTAL					**0.35**	**6.88**	**6.68**	**6.51**	**6.38**	**0.18**

FORMALDEHYDE EMISSIONS

Source	Emission Factor	unit	CH_2O lb/hr	CH_2O lb/day	CH_2O ton/year
			I_CH2O_pph	I_CH2O_ppd	I_CH2O_tpy
Incinerators					
Kulluk	0.00E+00	lb/ton	0.00	0.00	0.00
Ice Management	0.00E+00	lb/ton	0.00	0.00	0.00
Anchor Handler	0.00E+00	lb/ton	0.00	0.00	0.00
OSR vessel	0.00E+00	lb/ton	0.00	0.00	0.00
Quartering vessel	0.00E+00	lb/ton	0.00	0.00	0.00
			0.00	**0.00**	**0.00**

Source	pollutant	EF	unit
IC Engines-uncontrolled	CH_2O	1.59E-04	lb/gal
IC Engines-OxyCat controlled	CH_2O	4.78E-05	lb/gal
Boilers	CH_2O	3.30E-05	lb/gal
Incinerators	CH_2O	0.00E+00	lb/ton

*This activity cannot occur simultaneously with Resupply - DP mode. DP mode has greater impacts.

^Values in this column represent maximum emissions independent of activity.

Air Sciences Inc.	**PROJECT TITLE:** Shell - Exploration Drilling		**BY:** S. Pryor
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HAPs Emission Factors -(from AP42)

ICE Engines Emission Factors			*Boiler Emission Factors*			*Incinerator Emission Factors*
AP42 Table 3.3-2, Speciated Organic Compound Emission Factors For Uncontrolled Diesel Engines			**AP42 Table 1.3-9, Emission Factors For Speciated Organic Compounds From Fuel Oil Combustion**			
	EF			**EF**		
Pollutant	lb/MMBtu	lb/gal	**Pollutant**	$lb/10^3$ gal	lb/gal	
Acaldehyde	7.67E-04	1.04E-04				
Acenaphthene	1.42E-06	1.92E-07	Acenaphthene	2.11E-05	2.11E-08	
Acenaphthylene	5.06E-06	6.83E-07	Acenaphthylene	2.53E-07	2.53E-10	
Acrolein	9.25E-05	1.25E-05				
Anthracene	1.87E-06	2.52E-07	Anthracene	1.22E-06	1.22E-09	
Benzene	9.33E-04	1.26E-04	Benzene	2.14E-04	2.14E-07	
Benzo(a)anthracene	1.68E-06	2.27E-07	Benz(a)anthracene	4.01E-06	4.01E-09	
Benzo(a)pyrene	1.88E-07	2.54E-08				
Benzo(b)fluoranthene	9.91E-08	1.34E-08				
			Benzo(b,k)fluoranthene	1.48E-06	1.48E-09	
Benzo(g,h,l)perylene	4.89E-07	6.60E-08	Benzo(g,h,i)perylene	2.26E-06	2.26E-09	
Benzo(k)fluoranthene	1.55E-07	2.09E-08				
1,3-Butadiene	3.91E-05	5.28E-06				
Chrysene	3.53E-07	4.77E-08	Chrysene	2.38E-06	2.38E-09	
Dibenz(a,h)anthracene	5.83E-07	7.87E-08	Dibenzo(a,h)anthracene	1.67E-06	1.67E-09	
			Ethylbenzene	6.36E-05	6.36E-08	
Fluoranthene	7.61E-06	1.03E-06	Fluoranthene	4.84E-06	4.84E-09	
Fluorene	2.92E-05	3.94E-06	Fluorene	4.47E-06	4.47E-09	
Formaldehyde	1.18E-03	1.59E-04	Formaldehyde	3.30E-02	3.30E-05	
Indeno(1,2,3-cd)pyrene	3.75E-07	5.06E-08	Indo(1,2,3-cd)pyrene	2.14E-06	2.14E-09	
Naphthalene	8.48E-05	1.14E-05	Naphthalene	1.13E-03	1.13E-06	
Phenanthrene	2.94E-05	3.97E-06	Phenanthrene	1.05E-05	1.05E-08	
Pyrene	4.78E-06	6.45E-07	Pyrene	4.25E-06	4.25E-09	
Toluene	4.09E-04	5.52E-05	Toluene	6.20E-03	6.20E-06	
Xylenes	2.85E-04	3.85E-05				
			o-Xylene	1.09E-04	1.09E-07	
		5.23E-04			4.08E-05	

						Table 1.3-10. Emission Factors For Trace Elements From Distillate Fuel Oil Combustion Sources				**Table 2.2-2 - Metals Emission Factors for Mass Burn and Modular Excess Air Combustors**		
								EF				
Metal				lb/MMBtu	lb/gal	**Metal**		$lb/10^{12}$ Btu	lb/gal	**Metal**		lb/ton
Arsenic	As			4.90E-06	6.62E-07	Arsenic	As	4	5.40E-07	Arsenic	As	4.37E-03
Cadmium	Cd	11	$lb/10^{12}$ Btu	1.10E-05	1.49E-06	Cadmium	Cd	3	4.05E-07	Cadmium	Cd	1.09E-02
Chromium	Cr	0.35	$lb/10^6$ gal	2.59E-06	3.50E-07	Chromium	Cr	3	4.05E-07	Chromium	Cr	8.97E-03
Lead	Pb			2.9E-05	3.92E-06	Lead	Pb	9	1.22E-06	Lead	Pb	2.13E-01
Mercury	Hg	6.2	$lb/10^{12}$ Btu	6.20E-06	8.37E-07	Mercury	Hg	3	4.05E-07	Mercury	Hg	5.60E-03
Nickel	Ni	0.41	$lb/10^6$ gal	3.04E-06	4.10E-07	Nickel	Ni	3	4.05E-07	Nickel	Ni	7.85E-03
	Total Metals				7.66E-06	Total Metals			3.38E-06	Total Metals		2.51E-01
	Total HAPs				5.31E-04	Total HAPs			4.42E-05	Total HAPs		2.51E-01

Greatest Emited HAP		
Formaldehyde	1.59E-04	3.30E-05

ICE Metal References

Arsenic	L & E Air Emissions from Sources of Arsenic and Arsenic Compounds, EPA-454/R-98-013, June 1998, Table 4-20, Distillate Oil Fired Turbine
Cadmium	L & E Air Emissions from Sources of Cadmium and Cadmium Compounds, EPA-454/R-93-040, Sept. 1993, Table 6-12, No. 2 Distillate Oil
Chromium	L & E Air Emissions from Sources of Chromium, EPA-450/4-84-007g, July 1984, Table 36, Distillate #2
Lead	L & E Air Emissions from Sources of Lead and Lead Compounds, EPA 454/R-98-006, May 1998, Section 5.2.2, Distillate oil-fired gas turbines
Mercury	L & E Air Emissions from Sources of Mercury and Mercury Compounds, EPA-454/R-97-012, Dec. 1997, Table 6-12, Distillate No. 2
Nickel	L & E Air Emissions from Sources of Nickel, EPA-450/4-84-007f, March 1984, Table 26, Distillate #2

Total Annual Fuel	5,774,444	gallons
	779,550	MMBtu

Sulfur emission control by fuel quality

	% wt	EF	unit	SO_2 ton/year
Use of 100 ppm	0.0100%	0.0105	lb/MMBtu	4.096

Greenhouse Gas Emissions

CO_2e ($CO_2 + CH_4$*21 + N_2O*310)

Reference
40 CFR 98, Table A-1

		multiplier	EF	unit	ton/year	Reference
CO_2	comb	1	78.8	kg/MMBtu	**67,713**	Appendix B* Table B-3 [Distillate Fuel Oil (#1, 2, & 4)] May 2008
CH_4	comb	21	11	g/MMBtu	**199**	Appendix A* (Petroleum-Commercial) May 2008
$N_2$0	comb	310	0.6	g/MMBtu	**160**	Appendix A* (Petroleum-Commercial) May 2008
CH_4	offgas	21	399	lb	**4**	Methane Mass Caculation.xls October 22,2010
annual CO_2e (tons)					**68,076**	

* EPA Climate Leaders, Greenhouse Gas Inventory Protocol Core Module Guidance; "Direct Emissions from Stationary Combustion Sources"
http://www.epa.gov/climateleaders/documents/resources/stationarycombustionguidance.pdf

ATTACHMENT B

ENVIRON Memorandum: Meteorological Data Preparation for the Beaufort and Chukchi Seas

ENVIRON

February 22, 2011

MEMORANDUM

To: Tim Martin – Air Sciences

From: Ken Richmond - ENVIRON

Subject: Meteorological Data Preparation for the Beaufort and Chukchi Seas

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1 AERMOD Meteorological Data Input Files

The meteorological data sets for the AERMOD simulations in the Beaufort and Chukchi Seas were prepared using a combination of the EPA *Guideline* AERMET meteorological preprocessor and an alternative method for periods of open-water. The alternative approach bypasses the AERMET meteorological preprocessor using the Coupled Ocean Atmosphere Response Experiment (COARE) air-sea flux algorithm[1] and overwater meteorological measurements. ENVIRON compared this "COARE-AERMOD" approach to the current guideline OCD model[2] for conditions in the Arctic and also conducted a model performance evaluation using data from offshore tracer experiments to demonstrate the alternative COARE-AERMOD approach was not biased towards underestimates.[3]

AERMET was applied to data collected when the surface is characterized by sea-ice using characteristic geophysical parameters for such conditions in the Arctic. This is the same general EPA *Guideline* method for permitting onshore sources. Such conditions are prevalent at the beginning and end of the July through November offshore drilling season. For periods of open-water in the summer and fall, AERMET was replaced by the COARE air-sea flux algorithms applied to marine meteorological measurements supplemented by techniques to estimate characteristic mixing heights. The period of "open-water" is defined based on the availability of buoy data. In 2009 and 2010, Shell deployed buoys in the Chukchi and Beaufort Seas when the pack-ice allowed in late July or August. The buoys were in place until they were either destroyed or their operation affected by the pack-ice in October. The remainder of this section will describe the proposed methods for preparing the meteorological input files needed by AERMOD for these

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[1] Version 3.0 of the COARE algorithm with journal references and a User's Manual can be accessed at: ftp://ftp.etl.noaa.gov/users/cfairall/wcrp_wgsf/computer_programs/cor3_0/ and http://www.coaps.fsu.edu/COARE/flux_algor/

[2] ENVIRON 2010a. *Comparison of OCD vs. COARE-AERMOD, Support for Simulation of Shell Exploratory Drilling Sources in the Beaufort and Chukchi Seas.* ENVIRON, 19020 33rd Ave W, Suite 310, Lynnwood, WA 98036; Job No. 0322090, October 24, 2010.

[3] ENVIRON 2010b. *Evaluation of the COARE-AERMOD Alternative Modeling Approach, Support for Simulation of Shell Exploratory Drilling Sources In the Beaufort and Chukchi Seas.* ENVIRON, 19020 33rd Ave W, Suite 310, Lynnwood, WA 98036; Job No. 0322090, December 16, 2010.

two basic conditions: Sea-ice and Open-water. The discussion will focus on the Beaufort Sea data sets followed by modifications for the Chukchi Sea. A summary table of these issues has also been prepared and is attached.

1.1 Beaufort AERMET Sea-Ice Period

The modeling approach assumed the techniques embodied in AERMET are applicable to periods of the drilling season when the meteorology is not dominated by the effects of open-water. Open-water in this memorandum is defined as the period when the sea-ice allows the deployment of a buoy. The periods of the available Beaufort Sea buoy data are from August 5 and October 13, 2009; and August 14 and October 10, 2010. Prior to and following the open-water periods during the July to November drilling season, AERMET was applied using the same general techniques as are applied to permitting for onshore sources. The input parameters and data sources are:

- Onsite surface data: Surface data from the Reindeer Island 10 tower was used to provide wind speed, wind direction, air temperature, differential temperature between 10 m and 2 m, solar radiation and pressure.
- NWS data: NWS data from Deadhorse was collected and processed by AERMET. These data are primarily used for periods of missing onsite data as an alternative method for predicting the surface energy fluxes. Note, there are almost no missing Reindeer Island data for 2009 and 2010
- Optional horizontal and vertical turbulent intensities: Reindeer Island 10 m sigma-theta and sigma-w observations were included in the AERMET input files and passed through to AERMOD for dispersion estimates.
- Upper air data: Twice daily soundings from the Barrow NWS site were provided to AERMET for the prediction of the convective mixing heights and temperature gradients above the mixing height.
- Surface geophysical parameters: The albedo, Bowen ratio and the surface roughness length were set to 0.8, 2.0, and 0.001 m for the entire period. These settings were recommended by ADEC in recent previous permit applications for the Beaufort Sea.

1.2 Beaufort Sea COARE-AERMOD Overwater Data Set

The COARE-AERMOD meteorological data preparation involves two steps: 1) application of the COARE bulk air-sea flux algorithms to estimate the surface energy fluxes and 2) assembly of the meteorological data from the COARE algorithm with additional variables needed by AERMOD. A FORTRAN program was written that calls the COARE bulk air-sea flux algorithm subroutines provided by the authors of the method.[1] Mixing height estimates and several other variables needed by AERMOD are not part of the COARE routines. Mixing heights were provided separately using several techniques based on the data from the Endeavor Island thermal profiler. Further details are provided in the following discussion.

1.2.1 Data for COARE Algorithm

The COARE algorithm was applied to predict the surface energy fluxes from the overwater data sets briefly described above. The data necessary for the COARE algorithm depend on the options employed for estimating the surface roughness, for the treatment of a cool-skin, or heating of the upper layer of the ocean. The options and associated data are as follows:

- Several options are available to adjust the sea temperature to account for the difference between the skin temperature and the bulk temperature measurement taken at depth from a buoy or ship. Model comparison tests have shown the COARE algorithm is not sensitive to these options for conditions in the Arctic Ocean.[2] The cool-skin and warm layer options were not selected for the current study.
- COARE also contains several methods for estimating the surface roughness length, and the routines can use wave height and period measurement data. The simulations were conducted with the default option for a well-developed or deep sea. As with the warm-layer and cool-skin options, ENVIRON sensitivity tests suggest the COARE algorithm is not very sensitive to the surface roughness options, especially in the absence of wave measurement data.
- The air-sea temperature difference, overwater relative humidity and the wind velocity drive the energy fluxes and surface stability routines within the COARE routines. The air-sea temperature difference and humidity data were from buoy measurements. Shell deployed two buoys in the Beaufort Sea during both 2009 and 2010. The Reindeer Island buoy was used when these data were available supplemented by a buoy deployed by Shell near the Sivulliq prospect. The Sivulliq buoys extend the open-water periods in the 2009 and 2010 data sets. For each year, these buoys were left in the Beaufort Sea until they were destroyed by the pack-ice.
- The Reindeer Island 10 m observations were used for wind speed. Reindeer Island is a small offshore island with very little terrain relief, and the tower is located very close to the edge of the narrow island. It is assumed the 10 m winds are embedded within the marine boundary layer and are not influenced by the island. This assumption can be supported by comparisons with nearby offshore winds and air temperatures.
- Surface pressure is used to calculate air density and was also from the Reindeer Island observations.
- The COARE algorithm has a small term that depends on rainfall. Deadhorse Airport observations were provided for the calculations.
- The COARE algorithm has a small term for "gustiness" that adds to the momentum fluxes during light winds caused by large scale eddies. For COARE a constant estimate of 200m was assumed based on typical mixed layer heights in the Arctic during summer and fall.[4]

Surface energy flux estimates from the COARE algorithm were combined with measurements and reformatted according to the techniques discussed in the next section.

1.2.2 AERMOD Meteorological Data Assembly

The open-water meteorological data for the AERMOD simulations were prepared from the COARE algorithm estimates of the energy fluxes using the data described above and other measurements from the Arctic. The assembly of the necessary input data was accomplished in a

[4] Kahl, J.D. 1990. Characteristics of the Low-Level Temperature Inversion along the Alaskan Arctic Coast. *Int. J. of Climatology*, Vol. 10, 537-548.

spreadsheet, where the input data were reformatted to mimic the output from AERMET. The options selected for the simulations and associated data are as follows:

- Reindeer Island 10 m wind speed, wind direction, and air temperature data were used.
- Reindeer Island 10 m sigma-theta and sigma-w observations were passed through to AERMOD for dispersion estimates.
- Surface roughness lengths were estimated by the COARE algorithm using the default option for a well-developed sea based on friction velocity.
- Monin-Obukhov length (L) and surface friction velocity (u_*) were from COARE algorithm estimates. Based on the results of ENVIRON's comparisons to OCD and the model performance study, the Monin-Obukhov length were restricted such that ABS (L) > 5. This restriction avoids unrealistic extremely stable and unstable conditions during light wind conditions. For consistency, the surface friction velocity output from COARE was adjusted to impose such restrictions.
- Mixing heights for AERMOD were based on the results of a study examining the thermal profiler measurements at Endeavor Island during 2010. The boundary layer height was diagnosed from the profiler data during 2010 using an objective bulk Richardson number technique.[5] Comparisons of profiler diagnosed mixing heights to surface variables resulted in an empirical relationship for the prediction of the mixing height. This relationship was used during the 2009 period when the profiler data were not available. AERMOD requires both a mechanical and a connective mixing height. The mechanical mixing height was assigned to the profiler based estimate for all hours of data. The convective boundary layer height was set to the profiler based estimate during unstable conditions as indicated by the Monin-Obukhov length (L < 0). In order to avoid numerical problems and possible extrapolation of algorithms beyond their intended applications, the minimum mixing height was set at 25 m. Further details concerning the derivation of mixing heights are provided in:

  ENVIRON, 2010. *Evaluation of Profiler-Based Mixing Heights, COARE-AERMOD Alternative Modeling Approach, Support for Simulation of Shell Exploratory Drilling Sources In the Beaufort and Chukchi Seas*.

- Convective velocity scales were calculated from the convective mixed layer height (z_{ic}), friction velocity (u_*), and Monin-Obukhov length (L):

$$w_* = u_* \left(\frac{-z_{ic}}{0.4L}\right)^{1/3}$$

- The vertical potential temperature gradient above the convective boundary layer was derived from the Endeavor Island thermal profiler data during 2010. The gradient was based on the temperature difference observed in the layer 200 m above the convective mixing height. In the 2009 simulations, vertical potential temperature gradients were based on the average of the monthly median observations at Barter Island and Barrow from 1976-1985.[4] These monthly average values are: 0.023, 0.021, 0.019, 0.019, and 0.022 degrees per meter for July through November, respectively.

[5] Gryning, S.E. and Batchvarova, 2003. Marine Boundary-Layer Height Estimation from NWP Model Output. *Int. J. Environ. Pollut.* Vol 20, 147-153.

- Miscellaneous variables used by the AERMOD deposition algorithm (not used in the simulations):
  - Sensible heat fluxes were set to the estimates from the COARE algorithm.
  - Relative humidity data were from the buoy observations
  - Bowen ratios were calculated from the COARE predicted sensible and latent heat fluxes.
  - Albedo was set to the COARE default of 0.055.
  - The cloud cover fraction was from the Deadhorse NWS observations.
  - Precipitation amount and code was set as missing.
  - Surface pressure was from the Reindeer Island observations

1.3 Chukchi Sea AERMET Sea-Ice Period

The preparation of meteorological data for the Chukchi Sea follows the same basis principles as for the Beaufort Sea except different data sets were used. AERMET was applied during the periods of the year where meteorological conditions are dominated by the effects of sea-ice, while open-water periods were characterized using the COARE algorithm and buoy measurements. Prior to and following the open-water periods during the July to November drilling season, AERMET was applied using the same general techniques as are applied to permitting for onshore sources. The input parameters and data sources are:

- Onsite surface data: Data are not collected near the location of the Burger prospect during periods of sea-ice and onsite conditions during these periods were characterized using data collected by Shell at the Pt. Lay coastal site. For 2010, surface data from the Pt. Lay 10 m tower were used to provide wind speed, wind direction, air temperature, differential temperature between 10 m and 2 m, solar radiation and pressure. In 2009, data for the "onsite" AERMET pathway are not available and surface data from the Wainwright NWS station were used.
- NWS data: NWS data from Wainwright were collected and processed by AERMET. These surface observations of wind speed, temperature, cloud cover and other variables were used by AERMET to derive the surface energy fluxes in 2009. In 2010, these data were primarily used for periods of missing "onsite" Pt. Lay data.
- Optional horizontal and vertical turbulent intensities: Pt. Lay 10 m sigma-theta and sigma-w observations were included in the AERMET input files and passed through to AERMOD for dispersion estimates. These data are available for 2010.
- Upper air data: Twice daily soundings from the Barrow NWS site were provided to AERMET for the prediction of the convective mixing heights and temperature gradient above the mixing height.
- Surface geophysical parameters: As in the Beaufort Sea, the albedo, Bowen ratio and the surface roughness length were set to 0.8, 2.0, and 0.001 m for the entire period.

1.4 Chukchi Sea COARE-AERMOD Overwater Data Set

The offshore data available for the Chukchi Sea are less extensive than for the Beaufort Sea, especially during 2009 when only a month of data are available from a buoy deployed near the Burger prospect. In order to supplement these data during 2009, data from the Beaufort Sea buoys were used to extend the period of open-water data. In the simulations, the Chukchi "open-water" periods are August 5 to October 13, 2009; and July 27 to October 18, 2010. Further details concerning the application of the COARE bulk air-sea flux algorithms to estimate the surface energy fluxes and assembly of the meteorological data from the COARE algorithm with additional variables needed by AERMOD are provided in the following discussion.

1.4.1 Data for COARE Algorithm

The COARE algorithm was applied to predict the surface energy fluxes from the overwater data sets using the same basic assumptions as used in the Beaufort Sea. The COARE algorithm used the default option for estimating the surface roughness, cool-skin option turned off, and warm-layer heating turned off. The data sets are as follows:

- Buoy observations were used for the air temperature, air-sea temperature difference, overwater relative humidity, and the wind velocity for COARE flux estimates. Data from buoys near the Burger prospect are available during August 24, 2009 to September 30, 2009; and July 27, 2010 to October 18, 2010.

  In 2009, the Burger buoy missed a significant fraction of the open-water season. In order to compliment these data, observations from the Beaufort Sea were used to extend the open-water simulations from August 5 to October 13, 2009. Based on comparisons during periods where both data sets were available, conditions in the Chukchi Sea tended to be windier and the boundary layer more unstable than in the Beaufort Sea. Such tendencies will generally result in more dispersive conditions and the substitution of Beaufort overwater data will result in more conservative simulations.

- Surface pressure and precipitation were from the Wainwright NWS observations.
- The COARE algorithm has a small term for "gustiness" that adds to the momentum fluxes during light winds caused by large scale eddies. For COARE a constant estimate of 200m was assumed based on typical mixed layer heights in the Arctic during summer and fall.[4]

Surface energy flux estimates from the COARE algorithm were combined with measurements and reformatted according to the techniques discussed in the next section.

1.4.2 AERMOD Meteorological Data Assembly

The open-water meteorological data for the AERMOD simulations were prepared from the COARE algorithm estimates of the energy fluxes using the data described above and other measurements from the Arctic. The assembly of the necessary input data was accomplished in a spreadsheet, where the input data were reformatted to mimic the output from AERMET. The options selected for the simulations and associated data are as follows:

- Offshore wind speed, wind direction, and air temperature data from the Burger buoys were used when available. In 2009, wind speed and air temperature data were supplemented by data from the Beaufort Sea as explained above. During periods of overlapping data, wind directions in the Chukchi more closely resembles observations at

Wainwright. Wainwright NWS wind directions were used during open-water periods when data from the Burger buoy are not available in 2009.

- Optional offshore sigma-theta and sigma-w observations are not available for AERMOD and dispersion estimates were based on AERMOD's internal algorithms that parameterize these variables based on the surface energy fluxes and mixed layer heights.
- Surface roughness lengths were estimated by the COARE algorithm using the default option for a well-developed sea based on friction velocity.
- Monin-Obukhov length (L) and surface friction velocity (u_*) were from COARE algorithm estimates with the restriction that ABS (L) > 5.
- Boundary layer heights were estimated based on an analysis of the thermal profiler measurements at Endeavor Island during 2010. ENVIRON developed an empirical algorithm based on surface observations that provided good estimates of the mixing heights diagnosed from the profiler. This empirical relationship was used for both the mechanical and convective mixing heights for all simulations in the Chukchi Sea. In order to avoid numerical problems and possible extrapolation of algorithms beyond their intended applications, the minimum mixing height was set at 25 m. Further details concerning the derivation of mixing heights are provided in:

  ENVIRON, 2010. *Evaluation of Profiler-Based Mixing Heights, COARE-AERMOD Alternative Modeling Approach, Support for Simulation of Shell Exploratory Drilling Sources In the Beaufort and Chukchi Seas*.

- Convective velocity scales were calculated from the convective mixed layer height (z_{ic}), friction velocity (u_*), and Monin-Obukhov length (L)
- For all simulations in the Chukchi Sea, vertical potential temperature gradients were based on the average of the monthly median observations at Barter Island and Barrow from 1976-1985.[4] These monthly average values are: 0.023, 0.021, 0.019, 0.019, and 0.022 degrees per meter for July through November, respectively.
- Miscellaneous variables used by the AERMOD deposition algorithm (not used in the simulations):
  - Sensible heat fluxes were set to the estimates from the COARE algorithm.
  - Relative humidity data were from the buoy observations
  - Bowen ratios were calculated from the COARE predicted sensible and latent heat fluxes.
  - Albedo was set to the COARE default of 0.055.
  - The cloud cover fraction was from the Wainwright NWS observations.
  - Precipitation amount and code were set as missing.
  - Surface pressure was from the Wainwright or Pt. Lay observations

Table 1. Meteorological Preparation Summary

	2009 Ice Season	2009 Open Water	2010 Ice Season	2010 Open Water
Beaufort				
Wind Speed	Reindeer Island	Reindeer Island	Reindeer Island	Reindeer Island
Wind Direction	Reindeer Island	Reindeer Island	Reindeer Island	Reindeer Island
Temperature	Reindeer Island	Reindeer Island	Reindeer Island	Reindeer Island
Surface Flux	Solar-radiation, wind speed and ΔT from Reindeer Island	COARE based on Reindeer Island	Solar-radiation, wind speed and ΔT from Reindeer Island	COARE based on Reindeer Island
Air Sea ΔT	N/A	Reindeer Island Buoy (when available) and Sivulliq Buoy (when RI Buoy not available)	N/A	Reindeer Island Buoy (when available) and Sivulliq Buoy (when RI Buoy not available)
Mechanical Mix Ht.	AERMET u_* method based on Reindeer Island Data	Algorithm based on analysis of Endeavor Is. Profiler Data	AERMET u_* method based on Reindeer Island Data	Endeavor Island Profiler data
Convective Mix Ht.	AERMET method based on Barrow Soundings	Algorithm based on analysis of Endeavor Is. Profiler Data	AERMET method based on Barrow Soundings	Endeavor Island Profiler data
VPTG	AERMET method based on Barrow Soundings	Barter Island/Barrow 1976-1985 Mean	AERMET method based on Barrow Soundings	Endeavor Island Profiler data
Chukchi				
Wind Speed	Wainwright	Burger Buoy (when available) and RI Buoy/Sivulliq Buoy (when Burger Buoy not available)	Point Lay	Burger Buoy
Wind Direction	Wainwright	Burger Buoy (when available) and Wainwright NWS (when Burger Buoy not available)	Point Lay	Burger Buoy
Temperature	Wainwright	Burger Buoy (when available) and Reindeer Island Buoy/Sivulliq Buoy (when Burger Buoy not available)	Point Lay	Burger Buoy
Surface Flux	AERMET Method based on	COARE	Point Lay solar radiation, wind	COARE

Table 1. Meteorological Preparation Summary

	2009 Ice Season	2009 Open Water	2010 Ice Season	2010 Open Water
	Wainwright NWS data		speed, ΔT	
Air Sea ΔT	N/A	Burger Buoy (when available) and Reindeer Island Buoy/Sivulliq Buoy (when Burger Buoy not available)	N/A	Burger Buoy
Mechanical Mix Ht.	AERMET u_* based on Wainwright Data	Algorithm based on analysis of Endeavor Is. Profiler Data	AERMET u_* based on Point Lay Data	Algorithm based on analysis of Endeavor Is. Profiler Data
Convective Mix Ht.	AERMET method based on Barrow Soundings	Algorithm based on analysis of Endeavor Is. Profiler Data	AERMET method based on Barrow Soundings	Algorithm based on analysis of Endeavor Is. Profiler Data
VPTG	AERMET method based on Barrow Soundings	Barter Island/Barrow 1976-1985 Mean	AERMET method based on Barrow Soundings	Barter Island/Barrow 1976-1985 Mean

ATTACHMENT C

ENVIRON Profiler

Evaluation of Profiler-Based Mixing Heights, COARE-AERMOD Alternative Modeling Approach, Support for Simulation of Shell Exploratory Drilling Sources in the Beaufort and Chukchi Seas

1. Introduction

Shell Inc. (Shell) has developed an approach, under Section 3.0 in Appendix W of 40 CFR 51, to utilize an alternative technique to more accurately estimate concentration impacts in the Beaufort and Chukchi Seas. This technique uses an over-water meteorological preprocessor program that replaces the AERMET preprocessor program within the AERMOD modeling system. The standard version of AERMOD is then used for the dispersion modeling, to calculate concentrations. The replacement for AERMET is based on the results of the coupled atmosphere-ocean response experiment (COARE, *Fairall et al.*, 2003).

One of COARE's products was a FORTRAN coding of their revised ocean-atmosphere flux algorithm. The COARE v3.0 (2003) flux algorithm essentially solves the surface-layer similarity equations. It provides most of the inputs required by AERMOD, typically supplied via output files from AERMET: the surface (SFC) and profile (PFL) files given in AERMOD's "ME" stream. However, there are two parameters which are not provided by the COARE outputs: the mixing height (Z_i) and the vertical potential temperature gradient above the mixing layer (VPTG).

This document describes the methodology we applied to diagnose these two parameters. Of the two, predicted concentrations are more sensitive to changes in Z_i than to VPTG. This is because VPTG is used only to estimate overshooting of convective cells, while Z_i is used to scale some of the fundamental turbulence parameters.

Shell used data from a thermal profiler to diagnose Z_i and VPTG. For periods when the profiler was not operating, or for locations far from the profiler, we applied a statistical model that predicts Z_i based on near-surface observations. For those periods/locations, an average VPTG based on climatological average radiosonde data from Point Barrow and Barter Island were assumed.

2. The Profiler at Endeavor Island (Endicott)

Shell has contracted with the Hoefler Consulting Group (subsequently purchased by SLR) to operate a Kipp & Zonen MTP-5 version P profiler at its Endeavor Island facility (AKA Endicott) near Prudhoe Bay, Alaska. A picture of the device is shown in Figure 1, atop the shelter. The profiler can be seen in Figure 2 as well, along with the co-located 10 meter tower. The location of the installation is indicated in Figure 3. A representation of a typical installation is shown in Figure 4.

The profiler is a passive microwave radiometer that rotates from a horizontal to a vertical field of view, and provides estimates of temperature at 31 levels from 0 to 1000 meters above instrument height. Data levels are packed more tightly close to the surface (10 meter resolution) than near the highest levels (50 meter resolution). More information on the instrument can be found at http://www.attex.ru/mtp5.html.

The profiler and associated instrumentation package (co-located temperature at 2 and 10 meters, wind speed and direction) are located on a seaward section of the island, a few hundred meters from the main portion of the facility. The radiometer is oriented such that its field of view is over the ocean, to the north of the island. Because the radiometric path length is several hundred meters, this assures that the radiometer is measuring marine conditions.

Profiler quality assurance audits have been performed and submitted to the EPA. A number of high-resolution radiosonde launches have occurred as part of the Quality Assurance (QA) process. Co-located sondes were launched in April, August, and December 2010. The sonde data show reasonable agreement with the profiler retrievals. No radiometric method can resolve as fine-scale a structure as a sonde, because the path length (the distance over which the radiometer is effectively measuring a radiance) is not short enough. Were it shorter, then a radiometer would not be able to see "through" lower layers to measure values at altitude. More information on the quality assurance audits and profiler performance is available in the QA reports submitted to EPA.

Sample plots of temperature and potential temperature are shown in Figure 5 through Figure 8. The hypsometric equation was used to calculate pressure at the various levels above the surface, required to calculate potential temperature. The buoyancy effects of water vapor on the potential temperature were ignored, but are small in the arctic. Also shown in the plots are various levels of interest: *ZiBase* and *ZiTop* are the base and top of the inversion layer identified using a traditional definition (*Kahl*, 1990). *Zim* is the mechanical mixing height calculated by AERMET (*Venkatram*, 1980). *ZiRib* is the mixing height diagnosed from the profile using the critical bulk Richardson number method discussed below. *LCL* is the lifting condensation level of near-surface air, calculated using buoy data.

The first and second sample profiles show a typical low-level inversion, the latter with a secondary inversion aloft that is unimportant to surface processes. The last two sample profiles show deeper boundary layers, typical of the points in the lower lobe of points in Figure 10 and discussed in the statistical model section below.

Figure 1. The Kipp & Zonen MTP-5 profiler, with dual temperature sensors, installed at Endeavor Island.

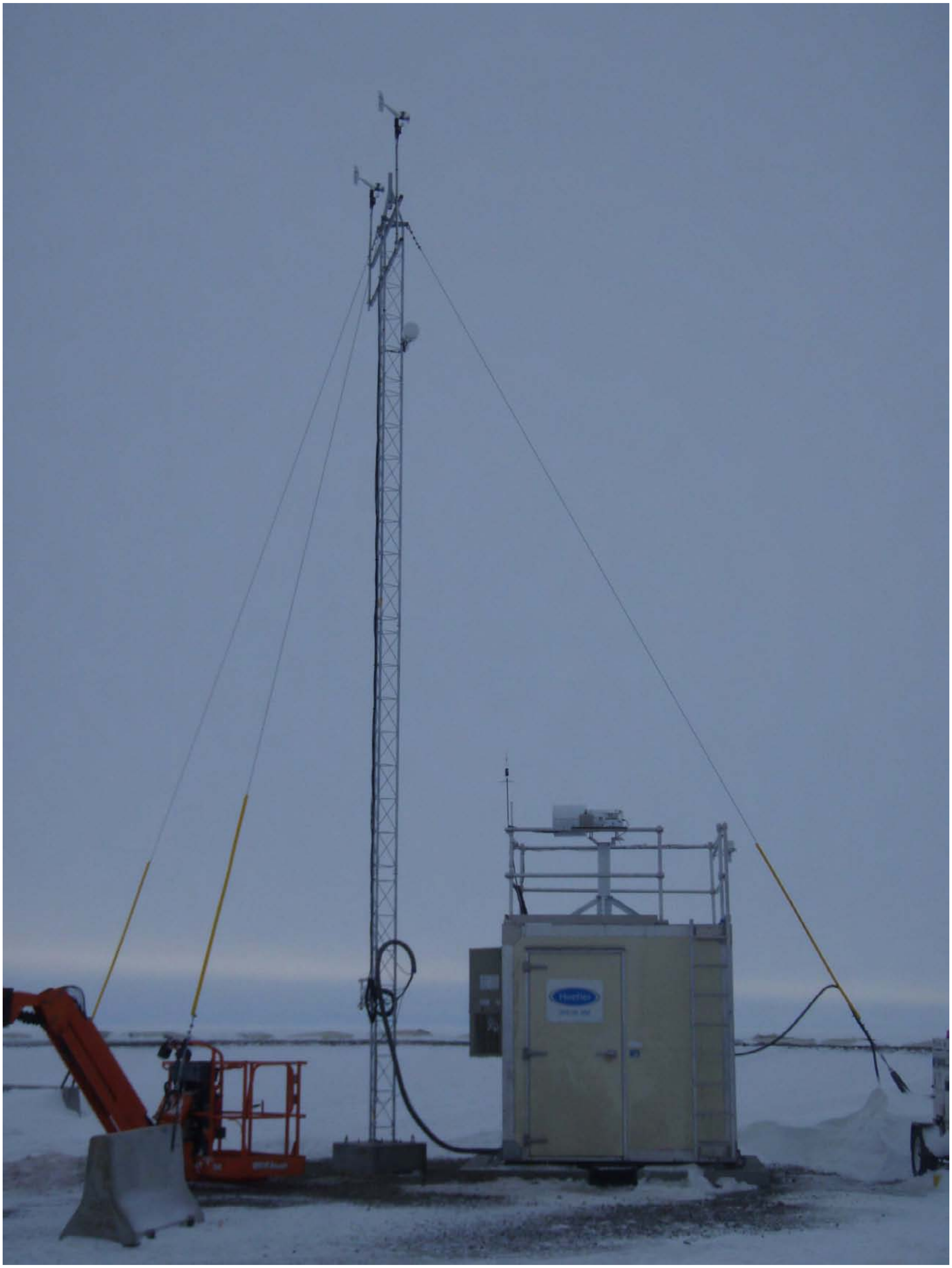

Figure 2. The installation, including the 10 meter tower and the K&Z profiler.

Figure 3. Location of the K&Z profiler at Endeavor Island.

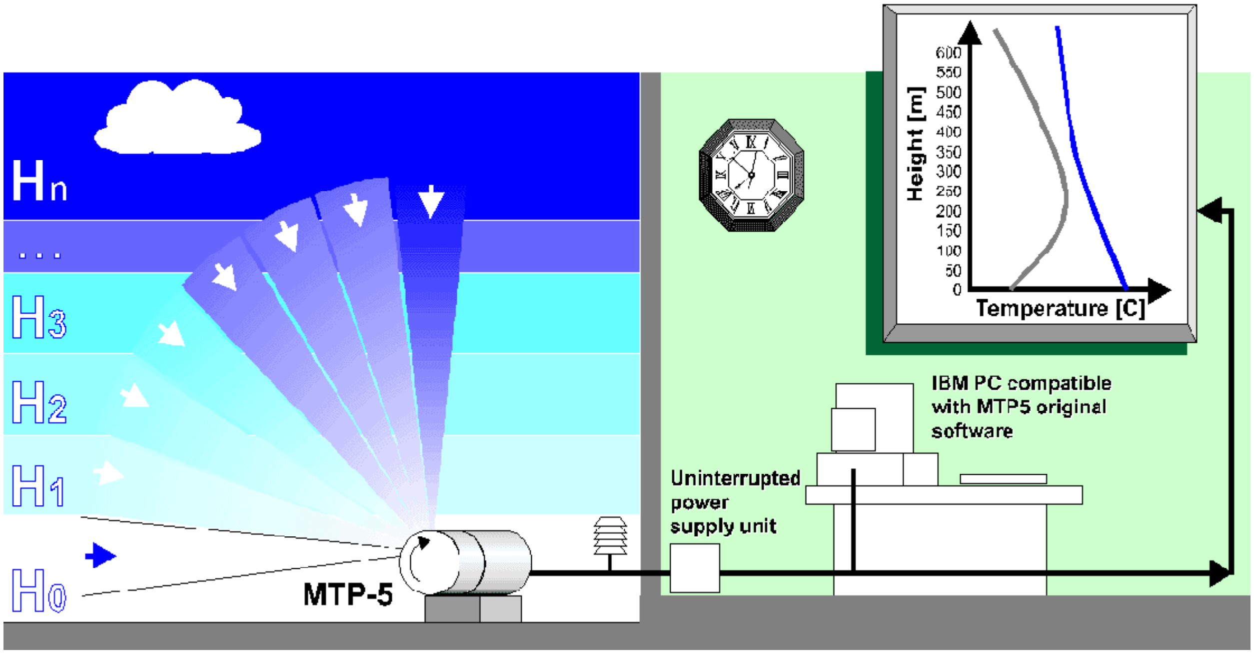

Figure 4. Typical operating scenario for an MTP-5.

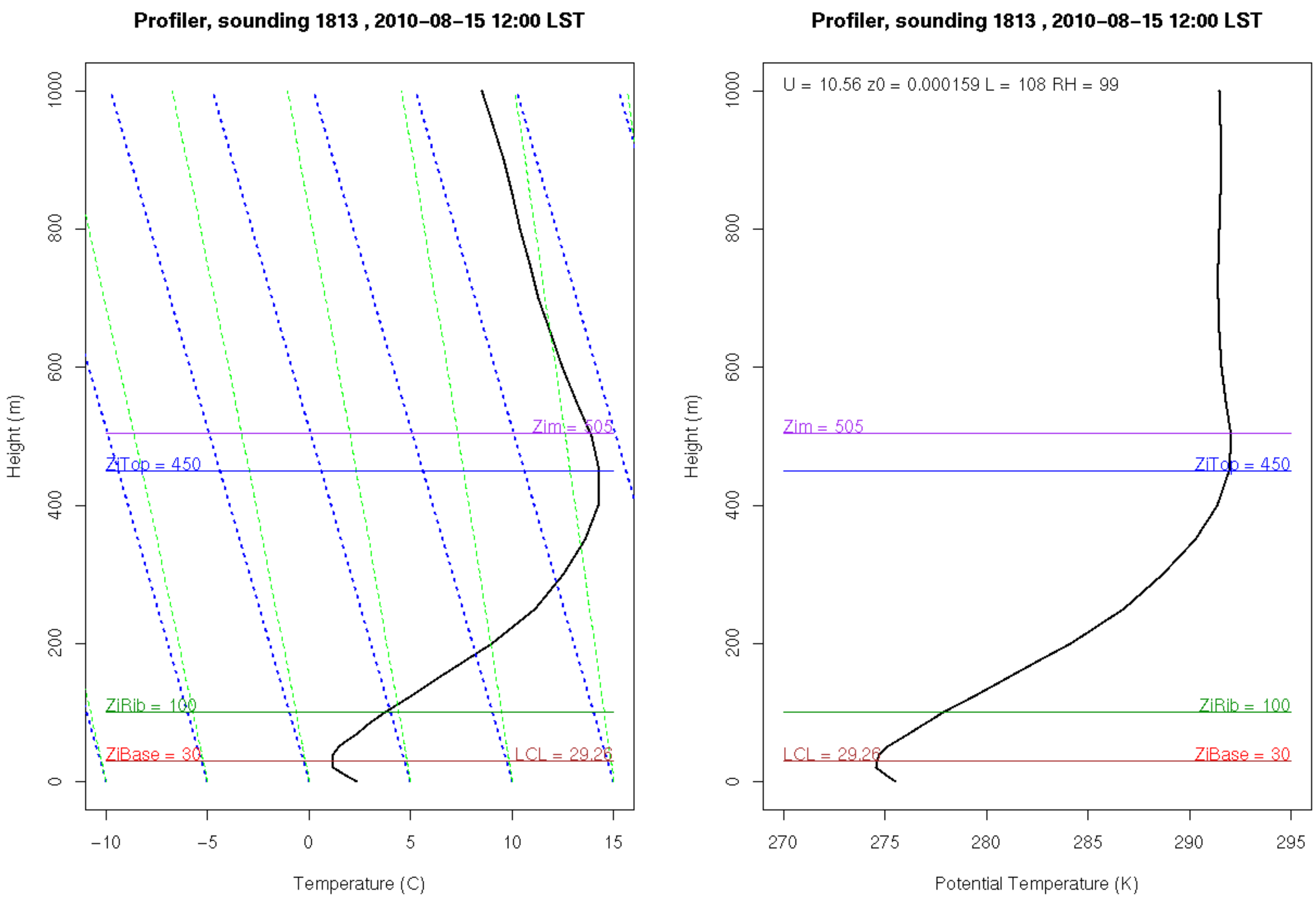

Figure 5. Temperature (left) and derived potential temperature (right) profiles from 12:00 LST on August 15, 2010.

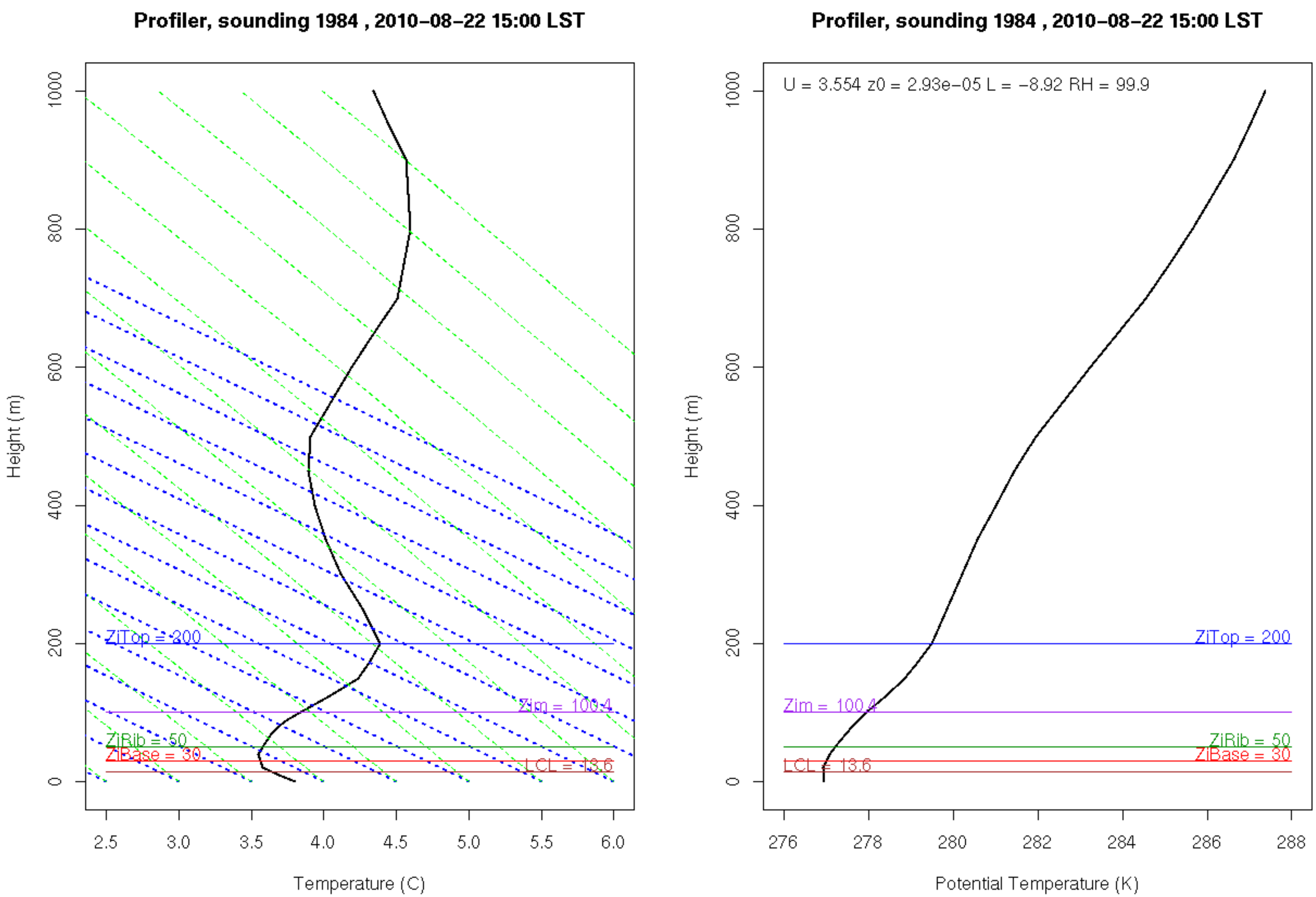

Figure 6. Temperature (left) and derived potential temperature (right) profiles from 15:00 LST on August 22, 2010.

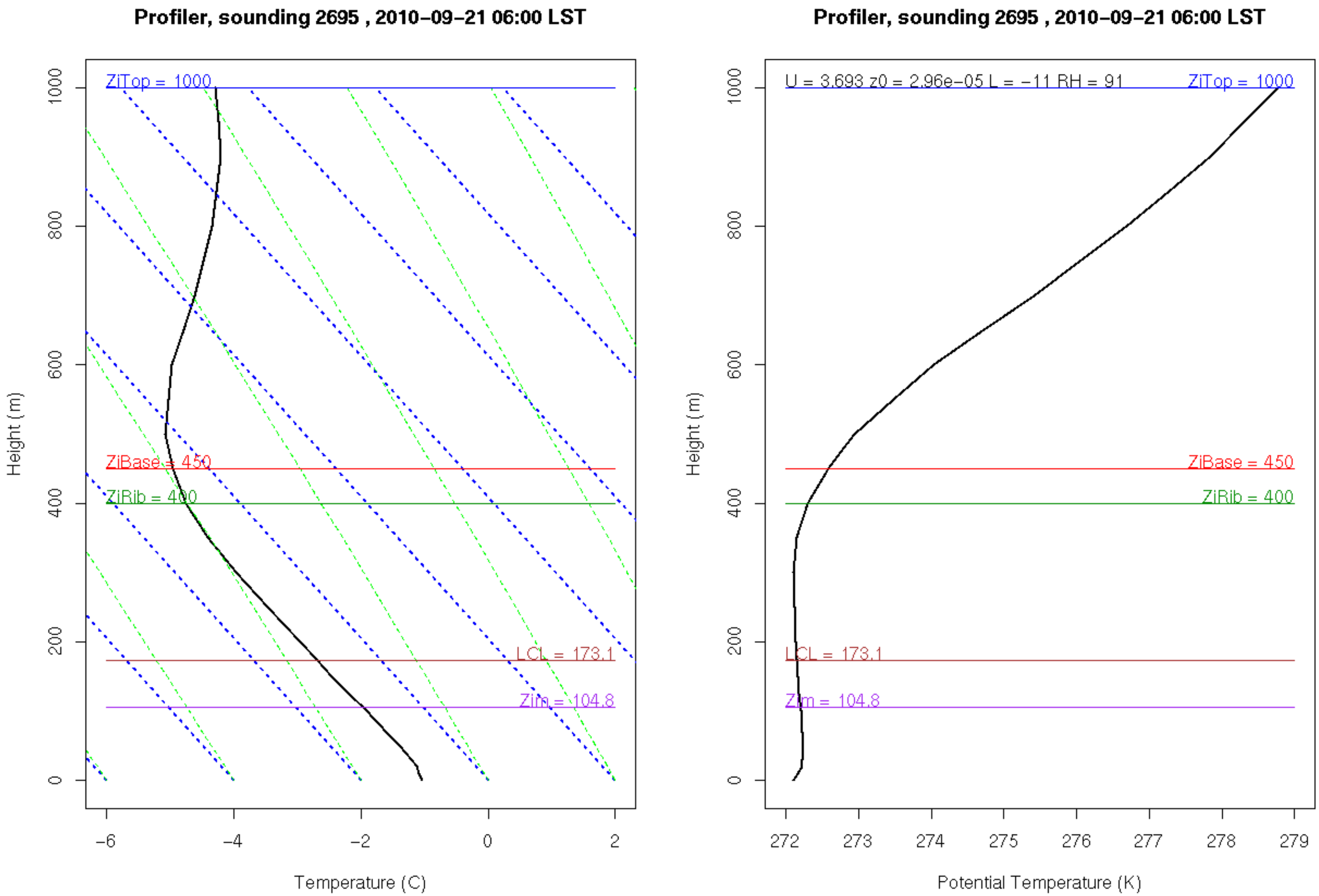

Figure 7. Temperature (left) and derived potential temperature (right) profiles from 6:00 LST on September 21, 2010.

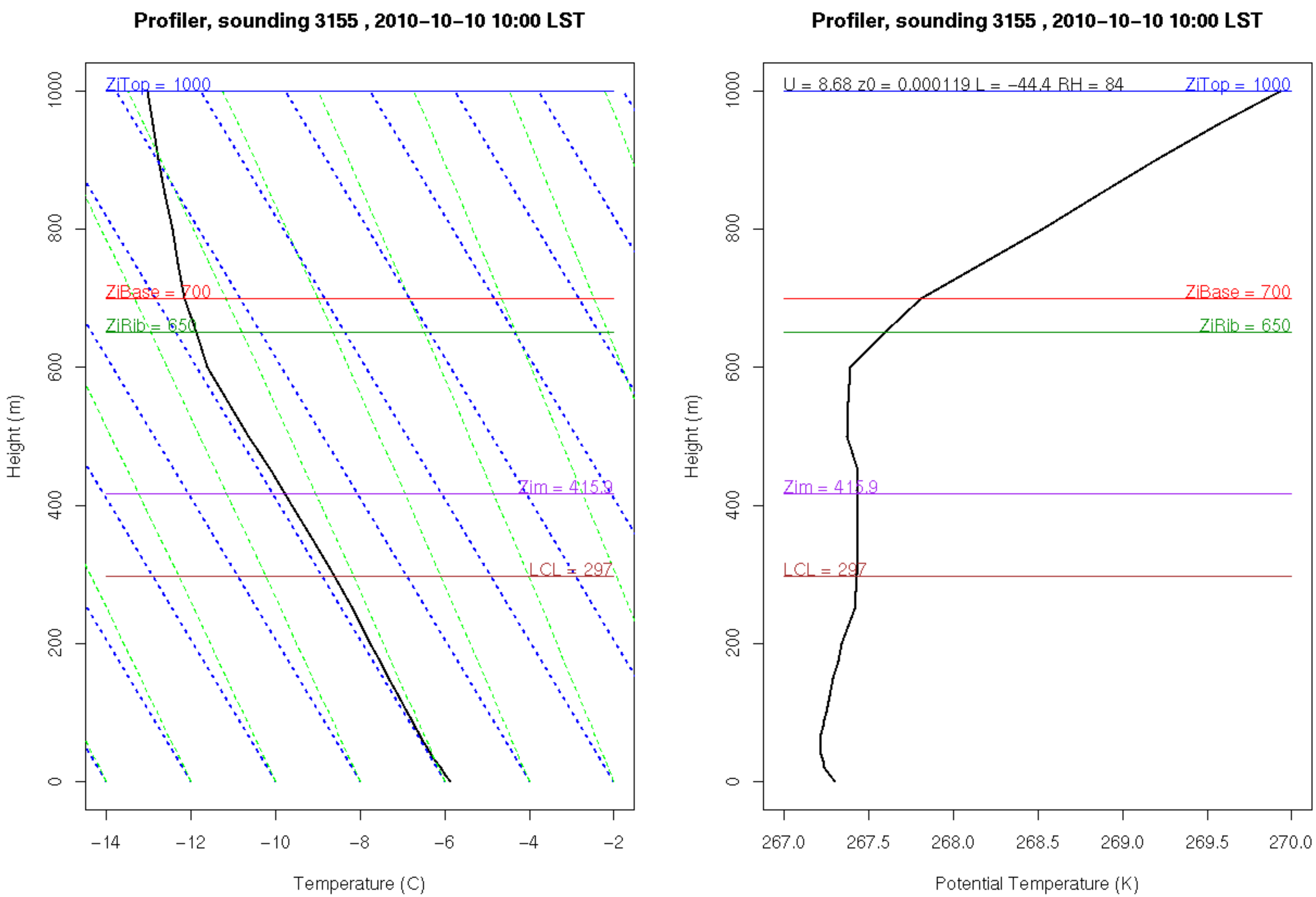

Figure 8. Temperature (left) and derived potential temperature (right) profiles from 10:00 LST on October 10, 2010.

3. Richardson Number

There is a long history in the literature of diagnosing mixing height or inversion height (Z_i, first used by *Deardorff*, 1972) based on profiles of temperature and wind. Many of these use the *Richardson Number*, *Ri*, named after Lewis Fry Richardson (1881 – 1953). It is a dimensionless number that expresses the ratio of potential to kinetic energy. It is essentially a comparison of the relative strengths of the vertical stability to the vertical shear. Its most basic definition is

$$Ri = \frac{gL}{u^2}$$

where *g* is the acceleration due to gravity, *L* is a representative length scale, and *u* is a representative speed. Small values of *Ri* indicate turbulence produced by vertical wind shear is overcoming the vertical stability, and vertical mixing is occurring. Large values of *Ri* indicate strong stability is overcoming the effects of wind shear, and turbulence is being effectively damped leading to poor vertical mixing.

Atmospheric scientists define a Richardson Number using a length scale and speed appropriate for the phenomenon they are studying, then use it as a scaling parameter to compare results in different locations or regimes. For example, it is common to define one for use in diagnosing deep convection (thunderstorms) in the Midwest, by choosing a length scale and speed appropriate for thermal convection. Other forms can be used to compare the details of hurricanes.

In the case of diagnosing surface-based mixing layers relevant to dispersion models like AERMOD, the common choice for the form of the Richardson Number is (e.g. *Leavitt et al.*, 1977)

$$Ri = \frac{g}{\theta} \frac{\frac{\partial \theta}{\partial z}}{\left(\frac{\partial u}{\partial z}\right)^2}$$

It compares the gradient of (potential) temperature to the gradient in wind speed. It is calculated at a point some distance above the surface, but is somewhat inconvenient to evaluate using common measurement techniques. It is difficult to measure $\partial\theta/\partial z$, but much easier to measure θ (or equivalently, temperature and pressure). Instead, a *Bulk Richardson Number* can be defined over some layer between z_1 and z_2. *Sørensen* (1998) suggested

$$Ri_b = \frac{g(z_2 - z_1)}{\theta(z_1)} \frac{\big(\theta(z_2) - \theta(z_1)\big)}{\big(u(z_2) - u(z_1)\big)^2}$$

This form has a serious numerical drawback when *u(z)* is constant, and Ri_b becomes undefined due to division by zero. A common variant of this equation is to include the surface friction velocity, u_* (*Vogelezang and Holtslag*, 1996) in the wind speed scaling:

$$Ri_b = \frac{g(z_2 - z_1)}{\theta(z_1)} \frac{\left(\theta(z_2) - \theta(z_1)\right)}{\left(u(z_2) - u(z_1)\right)^2 + bu_*{}^2}$$

where b is a parameterization constant, recommended by *Vogelezang and Holtslag* (1996) to be 100.

Over some layer, a strong difference in potential temperature will produce a larger Ri_b, and a strong wind speed shear will produce a smaller Ri_b. Well-mixed layers would have a small Ri_b, and poorly-mixed layers would have a large Ri_b.

The profiler does not measure wind speed aloft, only temperature. However, when using the COARE-AERMOD approach the values of u_* (friction velocity), z_0 (roughness length), L (Obukhov length) are all output from the COARE algorithm. Using standard Monin-Obukhov similarity theory (e.g. *Paulson*, 1970; *Liu, et al.*, 1979) the profile of wind speed can be calculated using

$$u(z) = \frac{u_*}{k}\left(\ln\left(\frac{z}{z_0}\right) - \Psi\left(\frac{z}{L}\right)\right)$$

where k is von Karman's constant (0.4) and Ψ is the stability correction function. For unstable conditions, $u(z)$ reaches a nearly constant value relatively close to the ground, and so does not change the value of Ri_b much above the surface layer. This allows Ri_b to be sensitive to elevated inversions above convectively mixed layers. For stable conditions (i.e. surface-based or near-surface inversions), Ri_b becomes large at low levels due to the large change of potential temperature, and the wind speed shear aloft is unimportant. This feature of the Monin-Obukhov model diminishes the negative effect of having to use a model for the vertical profile of wind speed.

4. Critical Richardson Number

Given an appropriate definition of the Richardson Number, a common technique used to diagnose the height of a well-mixed layer is to find the level at which Ri exceeds a critical value, Ri_{crit}. The level at which $Ri > Ri_{crit}$ is the mixing height, Z_i.

Sørensen (1998) and *Vogelezang and Holtslag* (1996) both suggest a value of Ri_{crit} = 0.25, though both were considering soundings taken over land. When diagnosing high-latitude marine boundary layers, *Gryning and Batchvarova* (2003) found better agreement using Ri_{crit} = 0.03 for Ri_b defined by *Sørensen* (1998), and using Ri_{crit} = 0.05 for Ri_b defined by *Vogelezang and Holtslag* (1996). This team of S.E. Gryning and E. Batchvarova is responsible for one of the most widely used and successful bulk models of the planetary boundary layer. In many journal articles, they are so commonly cited that it is often shortened to BG91, BG94, GB96, etc.

Hong and Kim (2008) suggested the critical bulk Richardson number for the determination of the stable boundary layer be set as a constant value of 0.25 over land, but be a function of the surface Rossby number (*Ro)* over the oceans, that is given by (*Vickers and Mahrt*, 2004)

$$Rib_{crit} = 0.16(10^{-7}Ro)^{-0.18}$$

This is the form used in the popular YSU boundary layer formulation available in the numerical weather models MM5 and WRF.

Although there is some variability as to the details of the form of the bulk Richardson number and the critical value used to identify the top of the mixing layer, in practical terms for the arctic oceans it makes little difference. Often, the observed temperature inversion is strong enough that all forms/values of Ri/Ri_{crit} are triggered at the same level. Using the traditional definition of an inversion base (the level at which the temperature starts to increase with height, *Kahl*, 1990) as "truth", it was impossible to pick any one of the forms/values over the others. Each method we tested (*Sørensen*, *Vogelezang and Holtslag*, *Hong and Kim*) were statistically the same, when compared to the traditional definition.

Given that the lower the value of Ri_{crit} the lower the diagnosed mixing height, it is conservative to use the value of 0.03 when applied to AERMOD dispersion modeling. Therefore, Ri_{crit} = 0.03 was used to diagnose the mixing height for all open water (not ice-covered) hours in 2010, using the profiler data and COARE-based wind shear.

VPTG, the vertical potential temperature gradient parameter, was then found by evaluating the slope of the potential temperature profile at Z_i + 200 meters, following the definition in the AERMOD formulation documents.

5. Profiler-Radiosonde Comparison of Diagnosed Mixing Heights

As part of the quality assurance procedures, a number of balloon-based radiosondes were launched very close to the profiler. Because the sondes report wind, temperature, and humidity information, a completely independent estimate of the mixing height can be found using the critical bulk Richardson number method. A total of 12 sondes were launched during the open-water period of 2010, but one sonde (launched 13:00 LST on 2010-08-17) did not report any levels below 367 meters and is discarded for the purposes of this comparison.

Figure 9 shows the mixing heights diagnosed from the 11 remaining sondes, using the critical bulk Richardson number approach, vs. those diagnosed from the profiler for the same hours. Both datasets used Ri_{crit} = 0.03. Using Ri_{crit} = 0.05 was very similar (R^2 = 74%, RMSE = 37, Bias = -30) but using Ri_{crit} = 0.25 performed clearly worse. Using the *Hong and Kim* (2008) surface Rossby number based critical bulk Richardson number yielded slightly worse results (R^2 = 66%, RMSE = 44, Bias = -32) than a constant Ri_{crit} = 0.03. However, with only eleven points, the statistical significance of these results is suspect.

The profiler-based mixing heights are biased low, in keeping with the conservative nature of this approach. The squared linear correlation coefficient is relatively high for geophysical data, and the root mean square error and bias are low compared to the range of diagnosed values. The excellent agreement of the two independent estimations of the mixing height supports the use of the profiler data in AERMOD dispersion modeling.

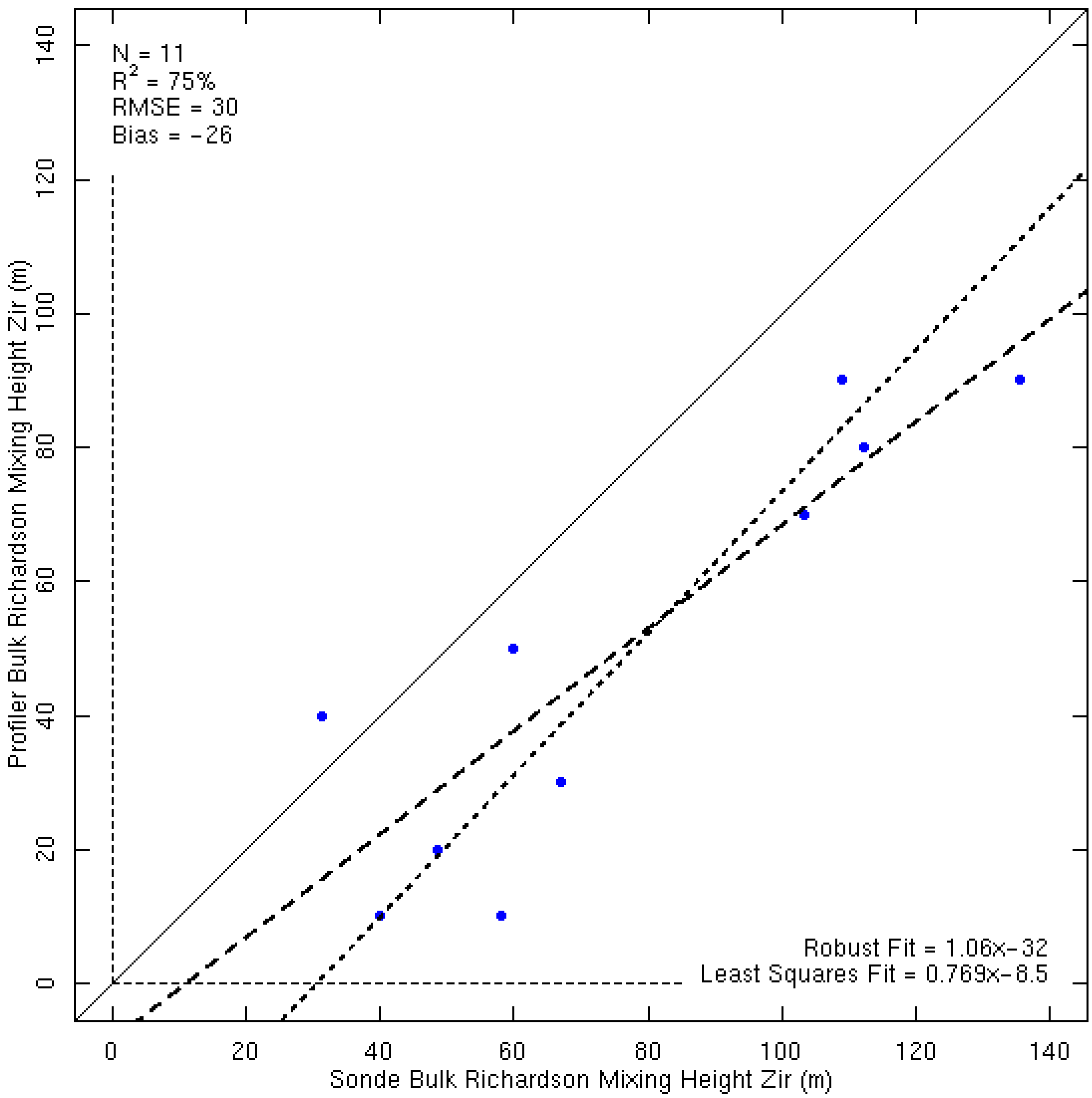

Figure 9. Critical bulk Richardson number diagnosed mixing heights from the Sondes vs. from the Profiler.

6. A Statistical Model for Mixing Height

A model that predicts the mixing height based on only surface observations would be extremely useful for periods, or locations, where the profiler is absent. AERMET predicts both a mechanical and convective mixing height, and AERMOD uses the larger of the two. As a starting point, the AERMOD mechanical mixing height (*Venkatram*, 1980) is compared with the mixing height diagnosed from the profiler data using Ri_{crit} = 0.03 in Figure 10. There is little agreement, with a squared linear correlation coefficient (R^2) of only 35%.

The Arctic Ice Dynamics Joint Experiment (AIDJEX) had several phases between 1970 and 1978 (*Untersteiner et al.*, 2007). In particular, during the 1975-76 field campaign the team had an acoustic radar profiler on the ice. Although not a perfect match for the ice-free conditions applicable to the COARE-AERMOD approach, both teams use a very similar formulation of surface layer similarity theory. A non-dimensional parameter useful for assessing the boundary layer that was in common use at the time (*Leavitt et al.*, 1978, *Carsey*, 1978) was fZ_i/u_*. This can be inverted to yield a simple formulation for the depth of the stable boundary layer:

$$Z_i = c\frac{u_*}{f}$$

where f is the Coriolis parameter. Values for c reported in the literature vary from 0.1 (*Arya*, 1977) to 0.15 – 0.25 (*Clarke and Hess*, 1973) in free convection, to 0.13 (*Carsey*, 1978) over arctic ice, to 0.125 (*Leavitt et al.*, 1978) also over arctic ice.

Using the AIDJEX formula and an appropriate scaling constant c was very similar to (performed no better or worse than) AERMOD's mechanical mixed layer height. Both show two relatively distinct branches of the data (Figure 10). Further investigation showed the branch with critical Richardson number heights much larger than the AIDJEX or Venkatram formula heights (i.e. the lower lobe of data points) was associated with deep, cloud-capped mixed layers. We hypothesize that the two lobes of data points are associated with bottom-up and top-down mixing processes. Most of the time, the Arctic boundary layer is driven, and well characterized, by surface fluxes (bottom-up mixing). Occasionally, a deeper layer develops that is driven by cloud-top cooling (top-down mixing).

Using the following conditions, the lower branch (deeper mixing layers) may be identified:

$$T_{v*} < -0.05$$

$$SLP \geq 1009\ mb$$

$$LCL > 0.6Z_{im}$$

$$u_* > 0.1\ m/s$$

where T_{v*} is the virtual temperature scaling parameter analogous to u_*, SLP is the sea level pressure, LCL is the lifting condensation level, Z_{im} is the mechanical mixing height predicted by AERMET (the Venkatram formula), and u_* is the friction velocity. All of these parameters are available from either the buoy/tower measurements themselves, or from the COARE algorithm.

The choice of these particular parameters is an attempt to capture the conditions under which top-down cloud-capped convection occurs. T_{v*} is a measure of bottom-up convection (a negative number indicates convective conditions) and filters out surface-based inversions. Selecting higher than average pressure chooses condition in which a synoptic-scale high produces subsidence that helps cap the inversion. The high lifting condensation level chooses relatively dry conditions, where the available moisture has been mixed over a deeper layer. And finally, requiring a modest u_* assures at least some winds, and precludes free convective conditions.

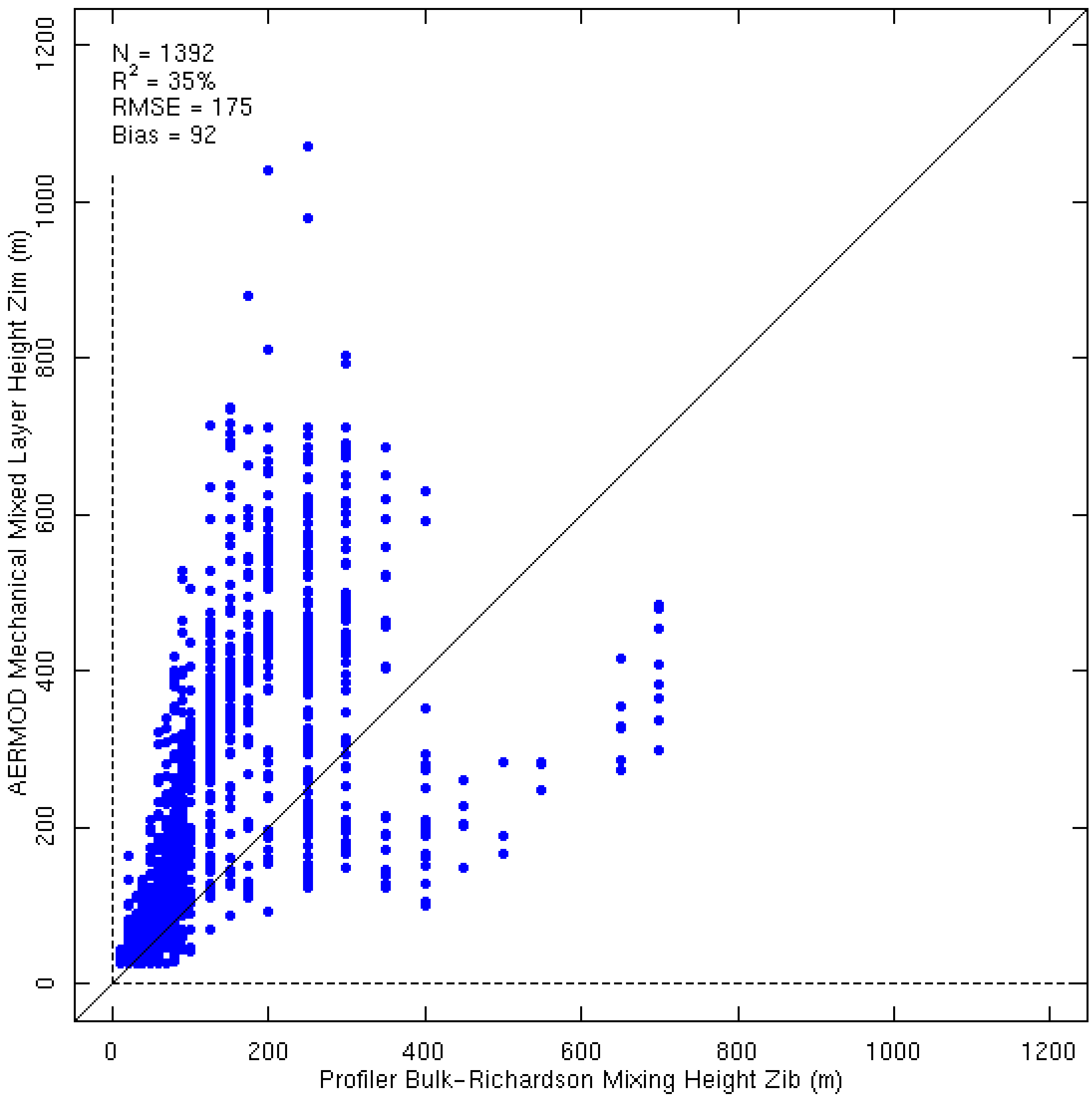

Figure 10. Mixing heights predicted by the Venkatram formula vs. diagnosed from the profiler.

For hours that fail to meet any of these four conditions, the model mixing height Z_{model} is found by using the AIDJEX formula with a constant c = 0.08 and assuming a latitude of 70 degrees. Equivalently:

$$Z_{model} = \frac{u_*}{1.8 \times 10^{-3}}$$

This value of c is less than most values in the literature, and about half that of the values found during AIDJEX. This is because of the use of 0.25 for the critical bulk Richardson number, which produces higher values of Z_i. Because we are using a value of 0.03, the corresponding constant c must be lower.

For points meeting all four of these conditions, the AIDJEX formula is co-linearly corrected using both u_* and w_* (the vertical velocity scaling parameter):

$$Z_{model} = \frac{u_*}{1.8 \times 10^{-3}}(3u_* + 4w_*) - 50$$

The definition of w_* is

$$w_* = u_* \frac{Z_i}{(-0.4L)^{1/3}}$$

This depends on Z_i, which in this case is the AIDJEX formula, the uncorrected mixing height. No iteration is performed on the model formula.

The resulting model values are plotted against the critical bulk Richardson diagnosed values for the 2010 open-water period in Figure 11. Note that 91% of the data points fall within the factor-of-two lines. The low root mean square error (RMSE), negligible bias, and high linear correlation coefficient (R^2) indicate a successful model that predicts the mixing height to within errors typical of dispersion models like AERMOD. The slight under-prediction of mixing height is conservative in terms of concentrations predicted by AERMOD.

7. Diagnosed versus Modeled Data Usage

The mixing heights (Z_i) diagnosed from the profiler data are appropriate for periods when the profiler was operational (May 2010 – present) and may be applied at locations in the Beaufort Sea. This could include Shell lease blocks near Sivulliq. Note that the profiler-based Z_i data are used only during the period of open water, and are not used during iced-over periods when AERMET is applied. VPTG is taken from the slope of the potential temperature profile at the level nearest Z_i + 200 meters.

Model-based Z_{model} mixing heights are appropriate for periods when the profiler was not operational and for locations far from Endeavor Island. This could include COARE-AERMOD analyses based on 2009 or 2010 buoy data from the Chukchi Sea, or 2009 buoy data in the Beaufort Sea. VPTG is taken from climatological averages calculated from the radiosonde data taken at Point Barrow and Barter Island by *Kahl* (1990).

Both of these methods produce hourly time series of values, which are used for both the mechanical and convective mixing heights in the SFC file input to AERMOD.

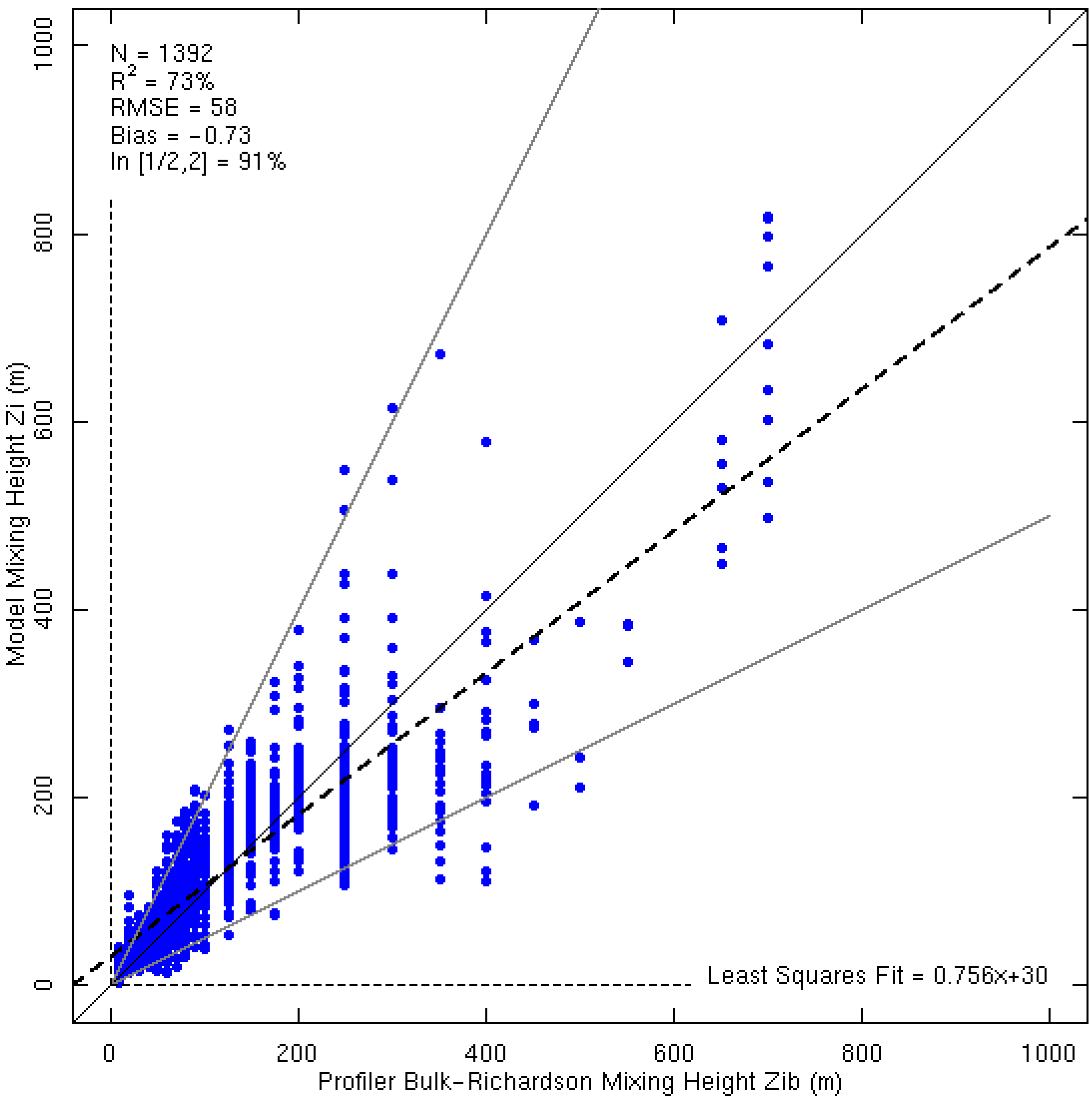

Figure 11. Mixing heights from the statistical model vs. diagnosed from the profiler.

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ATTACHMENT D

Measured NO_2/NOx Ratios for *Discoverer* Source

Stationary Source	Unit Description	Manufacturer or Vendor	Emission Unit Number	Size	Fuel Type	Combustor Equipment	Control Equipment	Data Source (CEM, Source Test)	Test Run	If Source Test, Load Level	Source or Test Year	NO2 PPMv	NO PPMv	NOx PPMv	NO2/NOx Ratio	Provided by	Concerned Load Level
Engines, All Controls																	
Discoverer	MLC Compressor	Caterpillar C-15	FD-9	540 hp	Diesel		OxyCat	Methods 1 - 4, 7E, 19	1	100%	2010	65	136.0	201.0	32.34%	*Emission Technologies, Inc.*	High
Discoverer	HPU Engine	Detroit 8V-71	FD-12	250 hp	Diesel		CDPF	Methods 1 - 4, 7E, 19	1	100%	2010	99	200.8	299.8	33.02%	*Emission Technologies, Inc.*	High
Discoverer	HPU Engine	Detroit 8V-71	FD-13	250 hp	Diesel		CDPF	Methods 1 - 4, 7E, 19	1	100%	2010	115	193.6	308.6	37.27%	*Emission Technologies, Inc.*	High
Discoverer	Cementing Unit	Detroit 8V-71N	FD-16	335 hp	Diesel		CDPF	Methods 1 - 4, 7E, 19	1	100%	2010	212	840.0	1,052.0	20.15%	*Emission Technologies, Inc.*	High
Discoverer	Cementing Unit	Detroit 8V-71N	FD-17	335 hp	Diesel		CDPF	Methods 1 - 4, 7E, 19	1	100%	2010	52	891.1	943.1	5.51%	*Emission Technologies, Inc.*	High
Nanuq	Port Main Engine	Caterpillar	N-1	2710 kW	Diesel		CDPF	Methods 1 - 4, 7E, 19	1	100%	2010	62	517.5	579.5	10.70%	*Emission Technologies, Inc.*	High
Nanuq	Starboard Main Engine	Caterpillar	N-2	2710 kW	Diesel		CDPF	Methods 1 - 4, 7E, 19	1	100%	2010	64	605.2	669.2	9.56%	*Emission Technologies, Inc.*	High
Nanuq	Aft Generator	Caterpillar	N-3	1285 hp	Diesel		CDPF	Methods 1 - 4, 7E, 19	1	100%	2010	42	812.8	854.8	4.91%	*Emission Technologies, Inc.*	High
Nanuq	Forward Generator	Caterpillar	N-4	1285 hp	Diesel		CDPF	Methods 1 - 4, 7E, 19	1	100%	2010	42	812.8	854.8	4.91%	*Emission Technologies, Inc.*	High
Discoverer	Generator Engine	Caterpillar D399	FD-5	1325 hp	Diesel		SCR, OxyCat	Methods 1 - 4, 7E, 19	1	600 kW	2010	1	17.0	18.0	5.56%	*Emission Technologies, Inc.*	Medium
Tor Viking II	Main Propulsion	MaK/6M32	TV-1	3784 hp	Diesel		SCR, OxyCat	Methods 1 - 4, 7E, 19	1	60%	2010	9	165.0	174.0	5.17%	*Emission Technologies, Inc.*	Medium
Tor Viking II	Main Propulsion	MaK/8M32	TV-2	5046 hp	Diesel		SCR, OxyCat	Methods 1 - 4, 7E, 19	1	60%	2010	12	150.0	162.0	7.41%	*Emission Technologies, Inc.*	Medium
Tor Viking II	Main Propulsion	MaK/8M32	TV-3	5046 hp	Diesel		SCR, OxyCat	Methods 1 - 4, 7E, 19	1	60%	2010	8	146.0	154.0	5.19%	*Emission Technologies, Inc.*	Medium
Tor Viking II	Main Propulsion	MaK/6M32	TV-4	3784 hp	Diesel		SCR, OxyCat	Methods 1 - 4, 7E, 19	1	60%	2010	18	95.0	113.0	15.93%	*Emission Technologies, Inc.*	Medium
Discoverer	MLC Compressor	Caterpillar C-15	FD-9	540 hp	Diesel		OxyCat	Methods 1 - 4, 7E, 19	1	50%	2010	65	169.6	234.6	27.71%	*Emission Technologies, Inc.*	Medium
Discoverer	HPU Engine	Detroit 8V-71	FD-12	250 hp	Diesel		CDPF	Methods 1 - 4, 7E, 19	1	50%	2010	102	135.9	237.9	42.88%	*Emission Technologies, Inc.*	Medium
Discoverer	HPU Engine	Detroit 8V-71	FD-13	250 hp	Diesel		CDPF	Methods 1 - 4, 7E, 19	1	50%	2010	112	126.6	238.6	46.94%	*Emission Technologies, Inc.*	Medium
Discoverer	Starboard Deck Crane	Caterpillar D343	FD-15	365 hp	Diesel		CDPF	Methods 1 - 4, 7E, 19	1	60%	2010	90	490.0	580.0	15.52%	*Emission Technologies, Inc.*	Medium
Discoverer	Logging Winch	Caterpillar C7	FD-19	250 hp	Diesel		CDPF	Methods 1 - 4, 7E, 19	1	50%	2010	25	124.8	149.8	16.69%	*Emission Technologies, Inc.*	Medium
Discoverer	Logging Winch	Caterpillar C7	FD-19	250 hp	Diesel		CDPF	Methods 1 - 4, 7E, 19	Average	50%	2010	23	167.3	190.3	12.09%	*Emission Technologies, Inc.*	Medium
Nanuq	Port Main Engine	Caterpillar	N-1	2710 kW	Diesel		CDPF	Methods 1 - 4, 7E, 19	1	50%	2010	58	511.9	569.9	10.18%	*Emission Technologies, Inc.*	Medium
Nanuq	Starboard Main Engine	Caterpillar	N-2	2710 kW	Diesel		CDPF	Methods 1 - 4, 7E, 19	1	50%	2010	57	562.3	619.3	9.20%	*Emission Technologies, Inc.*	Medium
Nanuq	Aft Generator	Caterpillar	N-3	1285 hp	Diesel		CDPF	Methods 1 - 4, 7E, 19	1	50%	2010	40	500.4	540.4	7.40%	*Emission Technologies, Inc.*	Medium
Nanuq	Forward Generator	Caterpillar	N-4	1285 hp	Diesel		CDPF	Methods 1 - 4, 7E, 19	1	50%	2010	39	497.0	536.0	7.28%	*Emission Technologies, Inc.*	Medium
Discoverer	Generator Engine	Caterpillar D399	FD-5	1325 hp	Diesel		SCR, OxyCat	Methods 1 - 4, 7E, 19	1	400 kW	2010	1	11.0	12.0	8.33%	*Emission Technologies, Inc.*	Other
Tor Viking II	Main Propulsion	MaK/6M32	TV-1	3784 hp	Diesel		SCR, OxyCat	Methods 1 - 4, 7E, 19	1	30%	2010	9	60.0	69.0	13.04%	*Emission Technologies, Inc.*	Other
Tor Viking II	Main Propulsion	MaK/6M32	TV-1	3784 hp	Diesel		SCR, OxyCat	Methods 1 - 4, 7E, 19	1	40%	2010	6	64.0	70.0	8.57%	*Emission Technologies, Inc.*	Other
Tor Viking II	Main Propulsion	MaK/6M32	TV-1	3784 hp	Diesel		SCR, OxyCat	Methods 1 - 4, 7E, 19	1	80%	2010	10	226.0	236.0	4.24%	*Emission Technologies, Inc.*	Other
Tor Viking II	Main Propulsion	MaK/8M32	TV-2	5046 hp	Diesel		SCR, OxyCat	Methods 1 - 4, 7E, 19	1	30%	2010	4	81.0	85.0	4.71%	*Emission Technologies, Inc.*	Other
Tor Viking II	Main Propulsion	MaK/8M32	TV-2	5046 hp	Diesel		SCR, OxyCat	Methods 1 - 4, 7E, 19	1	40%	2010	29	282.0	310.8	9.27%	*Emission Technologies, Inc.*	Other
Tor Viking II	Main Propulsion	MaK/8M32	TV-2	5046 hp	Diesel		SCR, OxyCat	Methods 1 - 4, 7E, 19	1	80%	2010	14	218.0	232.0	6.03%	*Emission Technologies, Inc.*	Other
Tor Viking II	Main Propulsion	MaK/8M32	TV-3	5046 hp	Diesel		SCR, OxyCat	Methods 1 - 4, 7E, 19	1	30%	2010	4	54.0	58.0	6.90%	*Emission Technologies, Inc.*	Other
Tor Viking II	Main Propulsion	MaK/8M32	TV-3	5046 hp	Diesel		SCR, OxyCat	Methods 1 - 4, 7E, 19	1	40%	2010	4	56.0	60.0	6.67%	*Emission Technologies, Inc.*	Other
Tor Viking II	Main Propulsion	MaK/8M32	TV-3	5046 hp	Diesel		SCR, OxyCat	Methods 1 - 4, 7E, 19	1	80%	2010	24	274.0	298.0	8.05%	*Emission Technologies, Inc.*	Other
Tor Viking II	Main Propulsion	MaK/6M32	TV-4	3784 hp	Diesel		SCR, OxyCat	Methods 1 - 4, 7E, 19	1	30%	2010	15	122.0	137.0	10.95%	*Emission Technologies, Inc.*	Other
Tor Viking II	Main Propulsion	MaK/6M32	TV-4	3784 hp	Diesel		SCR, OxyCat	Methods 1 - 4, 7E, 19	1	40%	2010	5	66.0	71.0	7.04%	*Emission Technologies, Inc.*	Other
Tor Viking II	Main Propulsion	MaK/6M32	TV-4	3784 hp	Diesel		SCR, OxyCat	Methods 1 - 4, 7E, 19	1	80%	2010	10	166.0	176.0	5.68%	*Emission Technologies, Inc.*	Other
Discoverer	Starboard Deck Crane	Caterpillar D343	FD-15	365 hp	Diesel		CDPF	Methods 1 - 4, 7E, 19	1	80%	2010	60	562.0	622.0	9.65%	*Emission Technologies, Inc.*	Other
Discoverer	Cementing Unit	Detroit 8V-71N	FD-16	335 hp	Diesel		CDPF	Methods 1 - 4, 7E, 19	1	70%	2010	227	623.0	850.0	26.71%	*Emission Technologies, Inc.*	Other
Discoverer	Cementing Unit	Detroit 8V-71N	FD-17	335 hp	Diesel		CDPF	Methods 1 - 4, 7E, 19	1	70%	2010	145	631.1	776.1	18.68%	*Emission Technologies, Inc.*	Other
Discoverer	Logging Winch	Caterpillar C7	FD-19	250 hp	Diesel		CDPF	Methods 1 - 4, 7E, 19	1	80%	2010	25	124.4	149.4	16.73%	*Emission Technologies, Inc.*	Other
Discoverer	Logging Winch	Caterpillar C7	FD-19	250 hp	Diesel		CDPF	Methods 1 - 4, 7E, 19	Average	80%	2010	27	120.6	147.3	18.11%	*Emission Technologies, Inc.*	Other
Nanuq	Port Main Engine	Caterpillar	N-1	2710 kW	Diesel		CDPF	Methods 1 - 4, 7E, 19	1	25%	2010	54	463.8	517.8	10.43%	*Emission Technologies, Inc.*	Other
Nanuq	Port Main Engine	Caterpillar	N-1	2710 kW	Diesel		CDPF	Methods 1 - 4, 7E, 19	1	75%	2010	59	552.2	611.2	9.65%	*Emission Technologies, Inc.*	Other
Nanuq	Starboard Main Engine	Caterpillar	N-2	2710 kW	Diesel		CDPF	Methods 1 - 4, 7E, 19	1	25%	2010	51	447.7	498.7	10.23%	*Emission Technologies, Inc.*	Other
Nanuq	Starboard Main Engine	Caterpillar	N-2	2710 kW	Diesel		CDPF	Methods 1 - 4, 7E, 19	1	75%	2010	60	599.0	659.0	9.10%	*Emission Technologies, Inc.*	Other

Stationary Source	Unit Description	Manufacturer or Vendor	Emission Unit Number	Size	Fuel Type	Combustor Equipment	Control Equipment	Data Source (CEM, Source Test)	Test Run	If Source Test, Load Level	Source or Test Year	NO2 PPMv	NO PPMv	NOx PPMv	NO2/NOx Ratio	Provided by	Concerned Load Level
Engines, No Controls																	
Vladimir Ignatuk	Port Generator Engine 1	Caterpillar/D399PC	VI-5	750 kW	Diesel		None	Methods 1 - 4, 7E, 19	1	625 kVA	2010	35	598.0	633.0	5.53%	*Emission Technologies, Inc.*	High
Vladimir Ignatuk	Starboard Generator Engine 2	Caterpillar/D399PC	VI-6	750 kW	Diesel		None	Methods 1 - 4, 7E, 19	1	625 kVA	2010	44	492.0	536.0	8.21%	*Emission Technologies, Inc.*	High
Tor Viking II	Harbor Generator	Caterpillar/3412	TV-5	1168 hp	Diesel		None	Methods 1 - 4, 7E, 19	1	90-100%	2010	24	344.0	368.0	6.52%	*Emission Technologies, Inc.*	High
Tor Viking II	Harbor Generator	Caterpillar/3412	TV-6	1168 hp	Diesel		None	Methods 1 - 4, 7E, 19	1	90-100%	2010	38	348.0	386.0	9.84%	*Emission Technologies, Inc.*	High
Harvey Spirit 280	Starboard Generator Engine 1	Cummins/KTA19-D(M)	FD-31-HS-3	485 kW	Diesel		None	Methods 1 - 4, 7E, 19	1	90-100%	2010	75	843	918	8.17%	*Emission Technologies, Inc.*	High
Harvey Spirit 280	Center Generator Engine 2	Cummins/KTA19-D(M)	FD-31-HS-4	485 kW	Diesel		None	Methods 1 - 4, 7E, 19	1	90-100%	2010	61	899	960	6.35%	*Emission Technologies, Inc.*	High
Harvey Spirit 280	Port Generator Engine 3	Cummins/KTA19-D(M)	FD-31-HS-5	485 kW	Diesel		None	Methods 1 - 4, 7E, 19	1	90-100%	2010	61	915	976	6.25%	*Emission Technologies, Inc.*	High
Harvey Explorer	Starboard Generator 1	Caterpillar/3406CDITA	FD-31-HE-4	320 kW	Diesel		None	Methods 1 - 4, 7E, 19	1	90-100%	2010	70	950	1,020	6.86%	*Emission Technologies, Inc.*	High
Harvey Explorer	Center Generator 2	Caterpillar/3406CDITA	FD-31-HE-4	320 kW	Diesel		None	Methods 1 - 4, 7E, 19	1	90-100%	2010	56	881	937	5.98%	*Emission Technologies, Inc.*	High
Harvey Explorer	Port Generator 3	Caterpillar/3406CDITA	FD-31-HE-5	320 kW	Diesel		None	Methods 1 - 4, 7E, 19	1	90-100%	2010	67	965	1,032	6.49%	*Emission Technologies, Inc.*	High
Kulluk	Electrical Generator Engines	EMD	K-1	2816 hp	Diesel		None	Methods 1 - 4, 7E, 19	Average	100%	2007	19.721	920.0	939.681	2.10%	*Alaska Source Testing, LLC*	High
Vladimir Ignatuk	Main Propulsion	Stork/8TM410	VI-1	5720 hp	Diesel		None	Methods 1 - 4, 7E, 19	1	60%	2010	60	600.0	660.0	9.09%	*Emission Technologies, Inc.*	Medium
Vladimir Ignatuk	Main Propulsion	Stork/8TM410	VI-2	5720 hp	Diesel		None	Methods 1 - 4, 7E, 19	1	60%	2010	69	589.0	658.0	10.49%	*Emission Technologies, Inc.*	Medium
Vladimir Ignatuk	Main Propulsion	Stork/8TM410	VI-3	5720 hp	Diesel		None	Methods 1 - 4, 7E, 19	1	60%	2010	75	642.0	717.0	10.46%	*Emission Technologies, Inc.*	Medium
Vladimir Ignatuk	Main Propulsion	Stork/8TM410	VI-4	5720 hp	Diesel		None	Methods 1 - 4, 7E, 19	1	60%	2010	76	596.0	672.0	11.31%	*Emission Technologies, Inc.*	Medium
Vladimir Ignatuk	Port Generator Engine 1	Caterpillar/D399PC	VI-5	750 kW	Diesel		None	Methods 1 - 4, 7E, 19	1	325 kVA	2010	42	502.0	544.0	7.72%	*Emission Technologies, Inc.*	Medium
Vladimir Ignatuk	Starboard Generator Engine 2	Caterpillar/D399PC	VI-6	750 kW	Diesel		None	Methods 1 - 4, 7E, 19	1	325 kVA	2010	32	401.0	433.0	7.39%	*Emission Technologies, Inc.*	Medium
Tor Viking II	Harbor Generator	Caterpillar/3412	TV-5	1168 hp	Diesel		None	Methods 1 - 4, 7E, 19	1	50-60%	2010	30	239.0	269.0	11.15%	*Emission Technologies, Inc.*	Medium
Tor Viking II	Harbor Generator	Caterpillar/3412	TV-6	1168 hp	Diesel		None	Methods 1 - 4, 7E, 19	1	50-60%	2010	40	172.0	212.0	18.87%	*Emission Technologies, Inc.*	Medium
Harvey Spirit 280	Port Main Engine	GE/7FDM12D5	HS-1	3070 hp	Diesel		None	Methods 1 - 4, 7E, 19	1	60%	2010	113	1,356	1,469	7.69%	*Emission Technologies, Inc.*	Medium
Harvey Spirit 280	Starboard Main Engine	GE/7FDM12D5	HS-2	3070 hp	Diesel		None	Methods 1 - 4, 7E, 19	1	60%	2010	95	986	1,081	8.79%	*Emission Technologies, Inc.*	Medium
Harvey Explorer	Port Main Engine	Caterpillar/3516BDITA	HE-1	2260 hp	Diesel		None	Methods 1 - 4, 7E, 19	1	60%	2010	65	865	930	6.99%	*Emission Technologies, Inc.*	Medium
Harvey Explorer	Stern Thruster	Caterpillar/3412EDITA	HE-9	540 hp	Diesel		None	Methods 1 - 4, 7E, 19	1	60%	2010	26	489	515	5.05%	*Emission Technologies, Inc.*	Medium
Kulluk	Electrical Generator Engines	EMD	K-1	2816 hp	Diesel		None	Methods 1 - 4, 7E, 19	Average	50%	2007	34.552	422.7	457.214	7.56%	*Alaska Source Testing, LLC*	Medium
Vladimir Ignatuk	Main Propulsion	Stork/8TM410	VI-1	5720 hp	Diesel		None	Methods 1 - 4, 7E, 19	1	40%	2010	50	505.0	555.0	9.01%	*Emission Technologies, Inc.*	Other
Vladimir Ignatuk	Main Propulsion	Stork/8TM410	VI-1	5720 hp	Diesel		None	Methods 1 - 4, 7E, 19	1	80%	2010	65	635.0	700.0	9.29%	*Emission Technologies, Inc.*	Other
Vladimir Ignatuk	Main Propulsion	Stork/8TM410	VI-2	5720 hp	Diesel		None	Methods 1 - 4, 7E, 19	1	40%	2010	36	405.0	441.0	8.16%	*Emission Technologies, Inc.*	Other
Vladimir Ignatuk	Main Propulsion	Stork/8TM410	VI-2	5720 hp	Diesel		None	Methods 1 - 4, 7E, 19	1	80%	2010	98	607.0	705.0	13.90%	*Emission Technologies, Inc.*	Other
Vladimir Ignatuk	Main Propulsion	Stork/8TM410	VI-3	5720 hp	Diesel		None	Methods 1 - 4, 7E, 19	1	40%	2010	55	335.0	390.0	14.10%	*Emission Technologies, Inc.*	Other
Vladimir Ignatuk	Main Propulsion	Stork/8TM410	VI-3	5720 hp	Diesel		None	Methods 1 - 4, 7E, 19	1	80%	2010	105	605.0	710.0	14.79%	*Emission Technologies, Inc.*	Other
Vladimir Ignatuk	Main Propulsion	Stork/8TM410	VI-4	5720 hp	Diesel		None	Methods 1 - 4, 7E, 19	1	40%	2010	63	475.0	538.0	11.71%	*Emission Technologies, Inc.*	Other
Vladimir Ignatuk	Main Propulsion	Stork/8TM410	VI-4	5720 hp	Diesel		None	Methods 1 - 4, 7E, 19	1	80%	2010	95	655.0	750.0	12.67%	*Emission Technologies, Inc.*	Other
Harvey Spirit 280	Port Main Engine	GE/7FDM12D5	HS-1	3070 hp	Diesel		None	Methods 1 - 4, 7E, 19	1	30%	2010	131	1,356	1,487	8.81%	*Emission Technologies, Inc.*	Other
Harvey Spirit 280	Port Main Engine	GE/7FDM12D5	HS-1	3070 hp	Diesel		None	Methods 1 - 4, 7E, 19	1	80%	2010	91	915	1,006	9.05%	*Emission Technologies, Inc.*	Other
Harvey Spirit 280	Starboard Main Engine	GE/7FDM12D5	HS-2	3070 hp	Diesel		None	Methods 1 - 4, 7E, 19	1	80%	2010	47	795	842	5.58%	*Emission Technologies, Inc.*	Other
Harvey Explorer	Port Main Engine	Caterpillar/3516BDITA	HE-1	2260 hp	Diesel		None	Methods 1 - 4, 7E, 19	1	35%	2010	82	908	990	8.28%	*Emission Technologies, Inc.*	Other
Harvey Explorer	Port Main Engine	Caterpillar/3516BDITA	HE-1	2260 hp	Diesel		None	Methods 1 - 4, 7E, 19	1	85%	2010	74	831	905	8.18%	*Emission Technologies, Inc.*	Other
Harvey Explorer	Stern Thruster	Caterpillar/3412EDITA	HE-9	540 hp	Diesel		None	Methods 1 - 4, 7E, 19	1	30%	2010	30	365	395	7.62%	*Emission Technologies, Inc.*	Other
Harvey Explorer	Stern Thruster	Caterpillar/3412EDITA	HE-9	540 hp	Diesel		None	Methods 1 - 4, 7E, 19	1	80%	2010	50	600	650	7.69%	*Emission Technologies, Inc.*	Other
Kulluk	Electrical Generator Engines	EMD	K-1	2816 hp	Diesel		None	Methods 1 - 4, 7E, 19	Average	35%	2007	35.518	322.1	357.597	9.93%	*Alaska Source Testing, LLC*	Other
Kulluk	Electrical Generator Engines	EMD	K-1	2816 hp	Diesel		None	Methods 1 - 4, 7E, 19	Average	75%	2007	4.009	689.8	693.847	0.58%	*Alaska Source Testing, LLC*	Other
Boilers, No Controls																	
Discoverer	Heat Boiler	Clayton 200	FD-21	7.97 MMBtu/hr	Diesel		None	Methods 1 - 4, 7E, 19	1	100%	2010	3	85.0	88.0	3.41%	*Emission Technologies, Inc.*	High
Discoverer	Heat Boiler	Clayton 200	FD-22	7.97 MMBtu/hr	Diesel		None	Methods 1 - 4, 7E, 19	1	100%	2010	4	80.0	84.0	4.76%	*Emission Technologies, Inc.*	High
Incinerator, No Controls																	
Discoverer	Incinerator	TeamTec GS500C	FD-23	276 lb/hr	Diesel		None	Methods 1 - 4, 7E, 19	1	70 kg/hr	2010	0.25	10.8	11.0	2.27%	*Emission Technologies, Inc.*	Medium

Source Group Averages

Source: Engines, All Controls

High (90-100%)	*17.60%*
Medium (50-60%)	*15.68%*

Source: Engines, No Controls

High (90-100%)	*6.57%*
Medium (50-60%)	*9.43%*

Source: Boilers, No Controls

All	*4.09%*

Source: Incinerator, No Controls

All	*2.27%*

Ship	***Source***	***Controls***	***Model ID***	***Ratio Avg to Apply***	***NO_2/NOx Ratio for Kulluk Modeling***
Kulluk					
	Generation	SCR + OxyCat	MAINENGS	Engines, All Controls	17.60%
	MLC HPU'S	OxyCat	MLCHPU	Engines, All Controls	17.60%
	Air compressors	OxyCat	AIRCMP	Engines, All Controls	17.60%
	Cranes	OxyCat	CRANE	Engines, All Controls	17.60%
	Heaters & Boilers	None	HEATBOIL	Boilers, No Controls	4.09%
	Incinerator	None	INCIN_K	Incinerator, No Controls	2.27%
	Seldom-used units	None	SELDOML (no egen.)	Engines, No Controls	6.57%
	Emergency Generator	None	SELDOMH (egen.)	Engines, No Controls	6.57%
Primary Ice Management			ICEMGMT; ICE MGMT/AH AREAPOLY	Engines, All Controls	17.60%
	Propulsion & Generation	SCR + OxyCat			
	Heaters & Boilers	None			
	Seldom-used units	None			
	Incinerator	None			
Secondary Ice Management / Anchor Handler					
	Propulsion & Generation	SCR + OxyCat			
	Heaters & Boilers	None			
	Seldom-used units	None			
	Incinerator	None			
Resupply Ship - DP mode			RESUP_DP	Engines, No Controls	6.57%
	Propulsion & Generation	None			
	Seldom-used units	None			
Resupply Ship - transport mode			RESUP_T	Engines, No Controls	6.57%
	Propulsion & Generation	None			
	Seldom-used units	None			
OSR vessel			OSR_MAIN; OSR Vessel AREAPOLY	Engines, No Controls	6.57%
	Propulsion & Generation	None			
	Seldom-used units	None			
	Incinerator	None			
Quartering vessel			OSR_QTR; Quartering Vessel AREAPOLY	Engines, All Controls	17.60%
	Propulsion & Generation	CDPF			
	Seldom-used units	None			
	Incinerator	None			
OSR work boats			OSR_WORK; OSR Work Boats AREAPOLY	Engines, No Controls	6.57%
	Work Boats	None			

ATTACHMENT E

Kulluk and Associated Fleet Modeling Parameters

Stack Parameters for Loads Analysis [2]

Source Description	Load	Mod. Src. ID	Source Type	Stack Orientation	Rel. Ht. [1] (m)	Exit Temp. (deg K)	Exit Vel. (m/s)	Stack Dia. (m)
Stack #1: Generation	100%	GEN_100	POINT	vertical	13.71	606	30.5	0.60
Stack #1: Generation	50%	GEN_050	POINT	vertical	13.71	482	28.2	0.60

Inputs for Loads Analysis - AERMOD [2]

	Actual Emissions (lb/hr)		Normalized Emiss. [3] (g/sec)		
Source Description	NO_x	$PM_{2.5}$	NO_x	$PM_{2.5}$	Load
Stack #1: Generation	50.17	2.97	1.000	1.000	100%
Stack #1: Generation	18.99	2.40	0.379	0.809	50%

Outputs for Loads Analysis - Max. AERMOD Impact

	1-Hour NOx (μg/m^3) Beaufort Sea		
Source Description	2009	2010	Load
Stack #1: Generation	106.2	163.1	100%
Stack #1: Generation	45.4	64.6	50%

Outputs for Loads Analysis - Max. AERMOD Impact

	24-Hour $PM_{2.5}$ (μg/m^3) Beaufort Sea		
Source Description	2009	2010	Load
Stack #1: Generation	20.3	21.1	100%
Stack #1: Generation	18.9	19.7	50%

[1] Above water level.

[2] Emissions and stack parameters are from Kulluk Stack Tests, 8/2007; 100% load emissions for $PM_{2.5}$ are based on the emissions inventory.

[3] Normalized emissions are based on the emissions at each load point (100% and 50%) divided by the emissions from the maximum load point (100%).

Building Information for Resupply Ship Analysis [1]

Ship Name	Harvey Spirit		Harvey Spirit		Arctic Seal		Arctic Seal	
Structure Name	Main Deck		Housing		Main Deck		Housing	
BPIP Name	RES_HS_M		RES_HS_Q		ARSEAL_M		ARSEAL_Q	
Height Above Water	4.57 m		15.24 m		1.52 m		7.62 m	
# Structure Corners	4		4		4		4	

Structure Corner #	Coordinate X(m)	Y(m)	Coordinate X(m)	Y(m)	Coordinate X(m)	Y(m)	Coordinate X(m)	Y(m)
1	47.4	31.6	92.2	75.3	73.2	64.1	72.1	63.0
2	110.0	89.7	103.3	85.6	44.3	35.2	64.6	55.5
3	97.5	103.1	93.0	96.8	37.4	42.1	57.7	62.4
4	35.0	45.0	81.8	86.4	35.0	45.0	65.2	69.9

[1] Both ships were analyzed in their respective resupply configurations near the Kulluk (i.e., Kulluk building information was also considered in the building downwash analyses for the resupply ships).

Stack Parameters for Resupply Analysis

Source Description	Mod. Src. ID	Source Type	Stack Orientation	Location X(m)	Location Y(m)	Rel. Ht. [2] (m)	Exit Temp. (deg K)	Exit Vel. (m/s)	Stack Dia. (m)
Harvey Spirit [3]	HARVEYSP	POINT	vertical	87.7	81.5	18.29	650	14.6	0.60
Arctic Seal [4]	ARCTICSL	POINT	vertical	65.5	63.3	8.61	644	40.0	0.26

[2] Above water level.

[3] Stack parameters for the Harvey Spirit are based on the average of stack tests from the Main Propulsion Engines (Port and Starboard) at the highest load point (80%).
ETI, 2010 M/V Harvey Spirit Main Propulsion Engine Port Engineering Testing Stack test report, 9/21/10
ETI, 2010 M/V Harvey Spirit Main Propulsion Engine Starboard Engineering Testing Stack test report, 9/21/10

[4] Stack parameters for the Arctic Seal are based on derived parameters from similar marine engines; engine specifications for the CAT3408's are not available.

* Also See Attachment F: Support Vessel Parameters

Emissions for Resupply Analysis

Source Description	Mod. Src. ID	Propulsion Power (hp)	Normalized Emissions [5] (g/sec)
Harvey Spirit	HARVEYSP	6,140	1.000
Arctic Seal	ARCTICSL	1,700	0.277

[5] Emissions for the resupply analysis are normalized based on the propulsion power levels for each ship.
For example, the Arctic Seal's propulsion power is appx. 28% of the Harvey Spirit 's (1,700 hp / 6,140 hp).

Outputs for Resupply Analysis - Max. AERMOD Impact

Source Description	Mod. Src. ID	1-Hour (μg/m^3) Beaufort Sea 2009	2010	24-Hour (μg/m^3) Beaufort Sea 2009	2010
Harvey Spirit	HARVEYSP	92.1	106.4	29.2	28.6
Arctic Seal	ARCTICSL	43.1	62.6	11.0	9.9

Building Information for Kulluk BPIP Analysis

Ship Name	Kulluk		Kulluk		Kulluk		Kulluk	
Structure Name	Helideck		Derrick Housing		Pipe Deck		Main Deck	
BPIP Name	HELIDECK		DERRICK		PIPEDECK		MAINDECK	
Height Above Water	17.98 m		34.75 m		14.63 m		7.31 m	
# Structure Corners	12		4		12		24	
Structure Corner #	**Coordinate X(m)**	**Y(m)**	**Coordinate X(m)**	**Y(m)**	**Coordinate X(m)**	**Y(m)**	**Coordinate X(m)**	**Y(m)**
1	10.8	-38.9	-12.2	-0.4	36.0	-8.7	-28.3	28.3
2	-13.2	-39.1	0.7	-13.3	32.2	-12.5	-19.8	34.8
3	-15.0	-37.3	12.9	-1.1	22.2	-2.4	-9.9	38.9
4	-22.2	-44.4	0.0	11.8	18.7	-5.9	0.7	40.3
5	-42.4	-24.0	---	---	-11.1	23.9	11.3	38.9
6	-35.3	-17.0	---	---	4.9	39.8	21.2	34.8
7	-37.2	-15.1	---	---	20.7	23.9	29.7	28.3
8	-36.8	8.7	---	---	27.1	30.3	36.2	19.8
9	-16.9	9.2	---	---	32.9	24.5	40.3	9.9
10	-16.7	-8.2	---	---	26.5	18.2	41.7	-0.7
11	-6.3	-18.6	---	---	40.2	4.4	40.3	-11.3
12	10.9	-18.3	---	---	31.6	-4.2	36.2	-21.2
13	---	---	---	---	---	---	29.7	-29.7
14	---	---	---	---	---	---	21.2	-36.2
15	---	---	---	---	---	---	11.3	-40.3
16	---	---	---	---	---	---	0.7	-41.7
17	---	---	---	---	---	---	-9.9	-40.3
18	---	---	---	---	---	---	-19.8	-36.2
19	---	---	---	---	---	---	-28.3	-29.7
20	---	---	---	---	---	---	-34.8	-21.2
21	---	---	---	---	---	---	-38.9	-11.3
22	---	---	---	---	---	---	-40.3	-0.7
23	---	---	---	---	---	---	-38.9	9.9
24	---	---	---	---	---	---	-34.8	19.8

Ship Name	Harvey Spirit		Harvey Spirit	
Structure Name	Main Deck		Housing	
BPIP Name	RESUPP_M		RESUPP_Q	
Height Above Water	4.57 m		15.24 m	
# Structure Corners	12		4	
Structure Corner #	**Coordinate X(m)**	**Y(m)**	**Coordinate X(m)**	**Y(m)**
1	47.4	31.6	92.2	75.3
2	110.0	89.7	103.3	85.6
3	97.5	103.1	93.0	96.8
4	35.0	45.0	81.8	86.4

ATTACHMENT F

Support Vessel Parameters

Harvey Spirit

Function: Resupply

Ship Dimensions
Length: 85.3 m
Width: 18.3 m
Propulsion: GE 7FDM 12 CYL
Reference: Vessel Specifications

Stack Parameters (propulsion engines)
Height: 18.29 m
Diameter: 0.6 m
Velocity: 14.6 m/s
Temperature: 650 K
References: Manufacturer specification
Velocity and diameter based on specification for other engines from same manufacturer
Stack height scaled from manufacturer drawing

Harvey Gulf Spirit

Stack Parameters

2/23/2011

Source Description	Release Ht. (ft)	Release Ht. (m)	Stack Dia. (ft)	Stack Dia. (m)	Exit Temp. (deg F)	Exit Temp. (deg K)	Exit Vel. (m/s)	Load %	Stack Area (m)	Avg. stack volumetric flowrate dscm/m	Avg. stack volumetric flowrate dscf/m	*Reference*
Harvey Spirit	60.0	18.29										
Port Main Engine			1.96	0.60	694.5	641.21	12.75	80%	0.28	91.04	3215	ETI, 2010 M/V Harvey Spirit Main Propulsion Engine Port Engineering Testing Stack test report, 9/21/10
Port Main Engine			1.96	0.60	576.1	575.43	7.61	60%	0.28	59.62	2105.33	ETI, 2010 M/V Harvey Spirit Main Propulsion Engine Port Engineering Testing Stack test report, 9/21/10
Port Main Engine			1.96	0.60	368.0	459.84	4.57	30%	0.28	46.37	1637.43	ETI, 2010 M/V Harvey Spirit Main Propulsion Engine Port Engineering Testing Stack test report, 9/21/10
Starboard Main Engine			1.96	0.60	724.5	657.85	16.49	80%	0.28	114.51	4044	ETI, 2010 M/V Harvey Spirit Main Propulsion Engine Starboard Engineering Testing Stack test report, 9/21/10
Starboard Main Engine			1.96	0.60	624.0	602.02	8.76	60%	0.28	65.35	2308.00	ETI, 2010 M/V Harvey Spirit Main Propulsion Engine Starboard Engineering Testing Stack test report, 9/21/10
Stack Parameters for Modeling												
Avg. Main Engines (80% Load)	60.0	18.29	1.96	0.60	709.5	649.5	14.6	80%				

Harvey Spirit 280

Unit Description	Make/Model	Rating	Serial Number
Port Main Engine	GE/7FDM12D5	3,070 hp	308995
Starboard Main Engine	GE/7FDM12D5	3,070 hp	308996
Starboard Generator Engine 1	Cummins/KTA19-D(M)	425 kW	37220567
Center Generator Engine 2	Cummins/KTA19-D(M)	425 kW	37220566
Port Generator Engine 3	Cummins/KTA19-D(M)	425 kW	37220326
Emergency Generator	Cummins/6BTAA5.9-G1	207 hp	
Bow Thrusters 1	Cummins/KTA38-D(M)	1,200 hp	
Bow Thrusters 2	Cummins/KTA38-D(M)	1,200 hp	
Stern Thrusters	Cummins/KTA38-D(M)	1,250 hp	33162077

Stack height 60.00 ft *Ref: HG 881 778 Air Draft to Stack-Spirit.pdf; photos*

Conversion 35.31467 m^3/ft^3

0.3048 m/ft

M/V HARVEY SPIRIT
"NEW DESIGN 280 FT."
OFFSHORE SUPPLY VESSEL
D.P.-2 CERTIFIED

DIMENSIONS AND REGULATORY

LENGTH:	280 FT.	BEAM: 60 FT	DRAFT: 16 1/2 FT LOADED
HULL DEPTH	19 1/2 FT.		
CERTIFICATION:	USCG SUBCHAPTER "L" & " I " OCEANS, SOLAS		
CLASSIFICATION:	ABS LOADLINE +A1, +AMS, DP-2, ACCU, Circle E NOTATION		
TONNAGE:	2261 GRT		

PERFORMANCE

SPEED/FUEL CONSUMPTION:	
Maximum:	13.0 KNOTS / 273 GPH
Cruise:	12 KNOTS

PROPULSION, MACHINERY AND DECK EQUIPMENT

MAIN ENGINES:	GE 7FDM (12 CYL)	HORSE POWER, TOTAL:	6,000 BHP
PROPELLERS:	HIGH EFFICIENCY CP	SIZE: 111 IN	(5) BLADE
GENERATORS:	THREE (3)	RATING: 3 X 425 KW	1275 KW TOTAL
	ONE (1)	1 X 99 KW	EMERGENCY UNIT
BOW THRUSTERS:	TWO (2) CONTROLLABLE PITCH	HORSE POWER:	TWO (2) @ 1250 BHP 2500 BHP TOTAL
STERN THRUSTER:	ONE (1) CONTROLLABLE PITCH	HORSE POWER:	ONE (1) @ 1250 BHP
RUDDERS:	INDEPENDENT HIGH LIFT		

CAPACITIES & DELIVERY RATES

DEADWEIGHT:	3,700	L.T. AT MAXIMUM DRAFT	CLEAR DECK:	202 X 52 FT	TOTAL SQ FT 10,500
DECK CARGO:	2,670	L.T.	DECK SAFE HAVENS:	YES	
RIG WATER:	325,000	GAL	DISCHARGE RATE:	800 GPM	
RIG FUEL:	261,856	GAL	DISCHARGE RATE:	800 GPM	
LIQUID MUD:	11,000	BBLS	DISCHARGE RATE:	1,200 GPM	@220' OF HEAD
METHANOL:	1,500	BBLS	DISCHARGE RATE:	100/500 GPM	@220' OF HEAD
			DISCHAR(RGE RATE:	100 TO 500 GPM	@220' OF HEAD
DRY BULK:	12,700	CU. FT.	SYSTEM PRESSURE:	80 PSI	
OFF SHIP FIREFIGHTING:	TWO (2) MONITORS		FLOW RATE:	5,000 GPM	

SPECIAL FEATURES

COMPUTERIZED TANK LEVEL INDICATOR SYSTEM/FULLY AUTOMATED	3 INDEPENDENT D.P. STATIONS
COMPUTERIZED VESSEL STABILITY MANAGEMENT PROGRAM	LIQUID MUD PIPE STRIPPING SYSTEM
COMPUTERIZED CARGO DISCHARGE SYSTEM	ERGONOMICALLY DESIGNED PILOTHOUSE
FUEL MANAGEMENT PROGRAM	3 RELATIVE POSITIONING SYSTEMS:
ONLINE COMMUNICATIONS	1) 2000 METER FAN BEAM
	2) "RADIUS"
	3) 4 X "DGPS"

ELECTRONICS

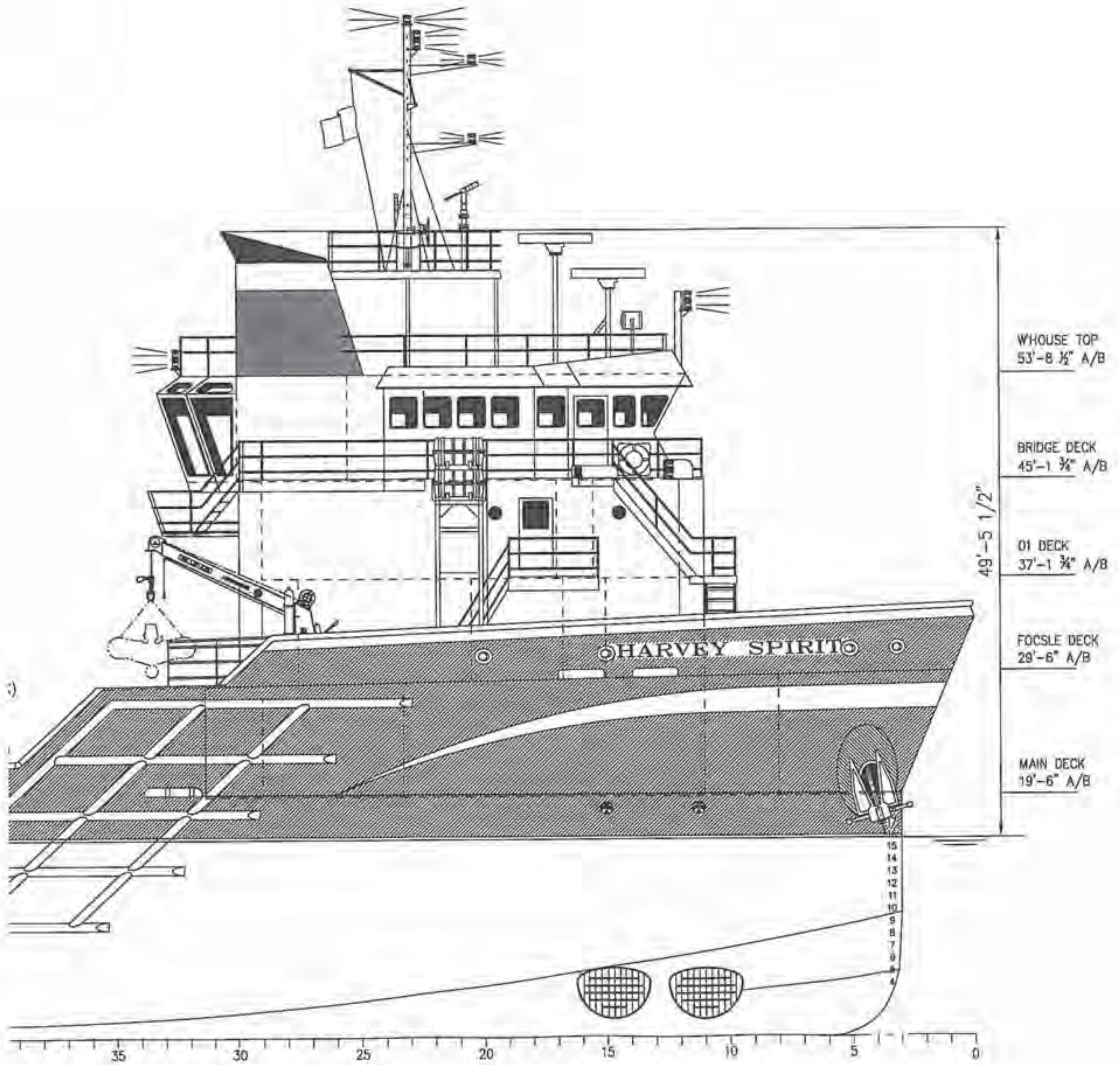
MAG COMPASS	GYRO COMPASS	JOYSTICK CONTROL (2)
AUTO PILOT	RADARS (2) 96 MI	FATHOMETER, 1,500M
SINGLE-SIDE BAND	SATELLITE "C"	VHF-FM (5)
GPS W/DIFFERENTIAL	D.P. (2) CERTIFIED	GMDSS "A3"

ACCOMMODATIONS

4-4 MAN ROOMS	1-2 MAN HOSPITAL
4-2 MAN ROOMS	
2-1 MAN ROOMS	

HARVEY GULF INTERNATIONAL MARINE, LLC

"Service with Safety & Efficiency"



OUTBOARD PROFILE

Arctic Seal

Function: Resupply

Ship Dimensions
Length: 40.8 m
Width: 9.75 m
Propulsion: CAT 3408
Reference: Vessel Specifications

Stack Parameters (propulsion engines)
Height: 8.61 m
Diameter: 0.26 m
Velocity: 40 m/s
Temperature: 644 K
References: Manufacturer specification
Velocity and diameter based on specification for other engines from same manufacturer
Stack height provided by ship operator

AIR SCIENCES INC. DENVER • PORTLAND	Air Sciences Inc. ENGINEERING CALCULATIONS	PROJECT TITLE: Shell Offshore, Inc.	BY: J. Firebaugh		
		PROJECT NO: 180-20-1	PAGE: 1	OF: 1	SHEET: 1
		SUBJECT: Arctic Seal Stack Parameters	DATE: January 25, 2011		

Arctic Seal Engine Information

Description	Make	Model	Rating	
Main Engine	Caterpillar	3408	850	hp
Main Engine	Caterpillar	3408	850	hp
Generator	Caterpillar	3306	90	kW
Generator	Caterpillar	3306	90	kW

Stack height 28.25 ft *Jack Rasmussen, Email: FW: stack height of Arctic Seal, May 12, 2010*

Used for modeling 8.61 m

Ratioed Stack Parameters

Make	Model	Rating	Exhaust Flow (m^3/min) @ load % 100%	80%	Exit Temp. (K)	Exit Vel. (m/s)	Stack Dia. (m)	Reference
Caterpillar	3412C	604 hp	92.1	73.1				Manufacturer Specification
Caterpillar	3608	3,634 hp			644			Manufacturer Specification

Arctic Seal Derived Stack Parameters

Make	Model	Rating	Exhaust Flow (m^3/min) @ load % 100%	80%	Exit Temp. (K)	Exit Vel. (m/s)	Stack Dia. (m)
Caterpillar	3408	850 hp	129.7	103.0	644	40	0.26

VESSEL SPECIFICATIONS
LANDING CRAFT "ARCTIC SEAL"

Landing Craft
Flag: U.S.
Built: 1978
Builder: Lantana Boatyard: Lantana, FL

Dimensions
LOA: 134.0ft
Beam: 32.0ft
Depth: 11.0ft
Light Mean Draft: 7.0ft
Loaded Mean Draft: 7Ft 10inch
GRT/NRT: 193.0/131.0

Classification
ABS Load line (expires 2/20/2010)
USCG Inspected (expires 5/23/2010)

Capacities
Deck Cargo: 260 tons w/housing
300 tons w/o housing
Clear Deck: 72' x 31'

Bulk
Potable water: 11,000gal
Fuel: 28,000gal

Recovered oil: 80,000gal

Accommodations
Quarters: 6 crew + 11
(Main House 9, Modules 8)
Galley: Yes

Propulsion
Engines: 2 ea Cat 3408
BHP: 850
Gears: Twin Disc MG514
Props: 2 each 54" x 42"
Rudder: 2
Speed 10 Knots
Fuel Consumption: 34-40gph

Auxiliary Equipment
Generators: 2each 90KW Cat 3306
Firefighting: Foam Fire Fighting System
Hydraulics: 2 each 25hp hydraulic pumps
Compressor: Lister emergency air compressor
Watermaker: Up to 1400 GPD
Moon Pool

Deck Machinery
Windlass: Hydraulic
Anchors: 2000# stern/500# bow
Chain/Wire: 1.25"
Crane: 7 ton hydraulic knuckle boom port forward
Ramp 14" wide
Winch: Single drum Markey/GM4-54
Linepull: 50,000# wire: 1.25"

ARCTIC SEAL

The ARCTIC SEAL (ex KRYSTAL SEA) was built for Arndt Brothers Construction Company of Homer, Alaska, as a 134 ft long landing craft and mini-bulk-oil tanker by Lantana Boat Yard in Florida in 1978. She was designed by James S. Krogen & Company, Inc. of Miami, Florida, to transport bulk diesel oil and construction equipment to remote Alaskan areas lacking port facilities. The ship was allowed to carry 103,000 gallons of bulk oil or 350 tons of deck cargo. She was propelled by twin Caterpillar 3408 diesel engines providing 730 horsepower to her shafts. She was equipped with a 2000 lb stern anchor and a 30,000 lb line pull winch to assist in pulling back off beaches after conducting cargo operations. Her cargo pump was capable of discharging the liquid bulk cargo ashore in eight hours. The ship was Coast Guard certified and classed by the American Bureau of Shipping. She has a 32 ft beam and was admeasured at 183 gross tons. Loaded she had a 7 ft 4 in draft. Now operated by Bering Marine Corporation of Anchorage, the ship continues to carry cargo around Western Alaska.

Pt. Oliktok

Function: Oil Spill Response (Primary)

Ship Dimensions
Length: 27.4 m
Width: 9.75 m
Propulsion: (2) Caterpillar V12 3512
Reference: Vessel Specifications

Stack Parameters (propulsion engines)
Height: 6.1 m
Diameter: 0.41 m
Velocity: 40 m/s
Temperature: 610 K
References: Manufacturer specification
Velocity and diameter based on specification for other engines from same manufacturer
Stack height scaled from manufacturer drawing

Air Sciences Inc. ENGINEERING CALCULATIONS	PROJECT TITLE: Shell Offshore, Inc.	BY: J. Firebaugh		
	PROJECT NO: 180-20-1	PAGE: 1	OF: 1	SHEET: 1
	SUBJECT: Point Oliktok Stack Parameters	DATE: February 14, 2011		

Point Oliktok Engine Information

Description	Make	Model	Rating	
Main Engine	Caterpillar	3512	1,055	hp
Main Engine	Caterpillar	3512	1,055	hp
Generator	Caterpillar	3304		
Generator	Caterpillar	3304		

Reference: specifications from vessel owner

Stack Parameters *(assuming 1 stack for 2 Cat 3512's)*

					Reference
Height	20	ft	6.10	m	Estimated from manufacturer's engineering drawing
Temperature	639	°F	610	K	Stack test data
Velocity	40	m/sec	40	m/sec	Estimate based on typical manufacturer exhaust stack design recommendations
Diameter	0.41	m	0.41	m/sec	Calculated based on flow (stack test data) and velocity (estimate)

Stack Test Data

Exhaust Flow	2,662	scfm
	5,626	acfm
Temperature	639	°F

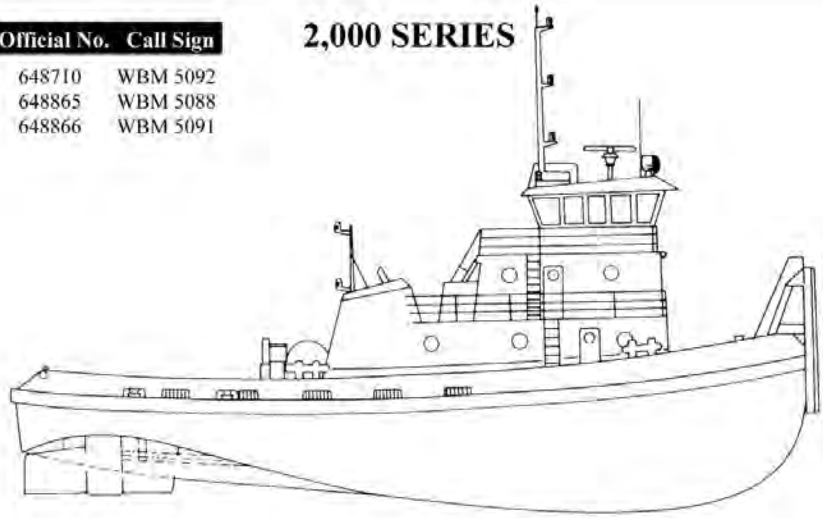
Reference: Caterpillar stack test performed 3/16/2000 on 3512 DITA Marine Engine @ 100% load, 1055 hp

Conversions

3.281	ft/m
60	sec/min
459.67	°R @ 0° F
1.8	Ratio - Rankine to Kelvin

Tug	Built	Official No.	Call Sign
PT. THOMPSON	1982	648710	WBM 5092
PT. BARROW	1982	648865	WBM 5088
PT. OLIKTOK	1982	648866	WBM 5091

2,000 SERIES



POINT-CLASS SPECIFICATIONS:

FLAG
United States

PORT OF REGISTRY
San Francisco, CA

BUILDER
Dakota Creek Shipyard
Anacortes, WA

OVERALL DIMENSIONS
Length: 90'
Breadth: 32'
Depth: 11' 6"

TONNAGE
147 tons gross
100 tons net

CONSTRUCTION
Steel / Aluminum

LIGHT DRAFT
6'

LOADED DRAFT
8' 6"

FUEL CAPACITY
60,000 gallons

POTABLE WATER
4,000 Gallons

LUBE OIL
650 Gallons

MAIN ENGINES
2 Caterpillar V12 3512

AUXILIARY ENGINES
2 Caterpillar 3304

PROPULSION
Twin-screw, 4-bladed
stainless steel, Kort nozzle

HORSEPOWER
2,110 maximum
continuous BHP

REDUCTION GEAR
Twin Disk MG 540,
ratio 6.18:1

TOWING WINCH
Smatco, single-drum

TOWING WIRE
1 @ 1,900' of
1 3/4" wire rope

EMERGENCY TOW GEAR
450' x 6" Spectra Line (SK-75)
Orville Hook
and appropriate
connecting gear
Line throwing gun.

BOLLARD PULL
47,000 lbs. ahead
45,000 lbs. astern
(Bollard pull will vary slightly
by vessel)

NAVIGATION / COMMUNICATIONS EQUIPMENT
Radar - Furuno 711
- Furuno 8100
Loran - Furuno LC90
GPS - Trimble Navtrac
VHF - SEA 156
- ICOM M-80
SSB - Motorola Triton Series

CROWLEY

Pier 17, 1102 SW Massachusetts P.O. Box 2287
Seattle, Washington 98111-2287 USA
Telephone: (206) 332-8000 Facsimile: (206) 332-8300
http://www.crowley.com

Crowley's tug and barge fleet of over 200 vessels includes tugs to 10,192 horsepower; oceangoing deck barges with single, double, or triple decks, ranging to 730 feet in length; harbor/river deck barges; house barges; and oil barges to 16,200 L/T deadweight. The Prince William Sound Class tugs are owned by a Crowley subsidiary - Vessel Management Services, Inc., and operated by Crowley Marine Services.

CATERPILLAR

Interoffice Memorandum

Facility	Engine Division
Date	March 16, 2000
Plant/ Office	Lafayette
Department	3500 Product Design
Attention	Phil Nace
CC:	

NOMINAL DATA
DO NOT USE FOR GUARANTEE PURPOSES

Plant or Office	Department	Attention	
		Request #	00009
Destroy	File Until (Date)		

The requested emissions data* presented below is based on tests conducted at Caterpillar Inc. using instrumentation equivalent to that outlined by ISO 8178 and the EPA code of federal regulations (40 CFR).

Engine Model: 3512 DITA running at 100% load, 1055 Hp at 1800 RPM, with wet manifolds.
Set at standard production timing. Arr#: 8N-5802 PL#: PL2956
Application: A continuous rated marine propulsion engine.

	Lb/Hr	g/Hr	g/Hp-Hr	PPM (Wet)	% BY Vol.	%BY Wt.
CO2	1244.7	564589	534.96	62554	6.26	10.26
N2	8998.6	4081655	3867.46	765816	76.58	74.15
O2	1375.9	624091	591.34	108929	10.89	11.34
H2O	492.5	223406	211.68	60704	6.07	4.06
CO	2.8	1287	1.22	242	0.02	0.02
NO~	17.3	7869	7.46		0.14	0.14
NOx~	26.5	12025	11.39	1380	0.00	0.00
HC	1.8	828	0.78	312	0.03	0.01
SO2^	1.6	717	0.68	59	0.01	0.01
TSP+	0.32	147.00	0.14			

	g/Hr	g/Hp-Hr	g/n cu.M'
NOx	12025	11.39	4.464
CO	1287	1.22	0.478
HC	828	0.78	0.307

SMOKE (Cat Number)..... 0.090
FUEL RATE............... 395.59 Lb/
INLET AIR FLOW.......... 11740 Lb/Hr
EXHAUST FLOW:
Rate.................... 12135 Lb/H
at 60 deg F and 760mm Hg. 2662 SCFM
at 639 deg F stack temp. 5626 CFM

Notes: * This data is based on steady-state engine operating conditions of 77 deg. F and 28.35 in. Hg. and No. 2 diesel fuel. This data is also subject to instrumentation, measurement and engine-to-engine variations.

~ The NOx shown is not actually present in the exhaust. It is based on the assumption that the NO present in the exhaust is converted to NO2 in the atmosphere. NO and NOx are corrected to 75 grains humidity.

^ SO2 is proportional to a sulfur content of 0.20 % by weight of the fuel.

+ TSP (Total suspended Particulate) is an actual measurement using an ISO 8178 micro-dilution system.

' Grams per normal cubic meter values are corrected to 5% oxygen.

This report provides the best information available at this time. It should not be used at a future date without verification as to its validity for the current engine.

Kevin L. Claytor
Robert Maxson
3500 Current Perf. & Emis.
Ext. 5907

Nanuq

Function: Oil Spill Response

Ship Dimensions
Length: 91.7 m
Width: 18.3 m
Propulsion: (2) Caterpillar 3608
Reference: Vessel Specifications

Stack Parameters (propulsion engines)
Height: 15.24 m
Diameter: 0.76 m
Velocity: 40.0 m/sec
Temperature: 644 K
References: Manufacturer specification
Velocity and diameter based on specification for other engines from same manufacturer
Stack height scaled from manufacturer drawing

OSRV - *NANUQ*
GENERAL SPECIFICATIONS

Vessel Name	Nanuq (formerly Hull 240, now Hull 235)
Principal Dimensions	301'6" x 60" x 24'
Horsepower	7,200 BHP
Deck Space	169' x 50.5'
Main Engines	(2) 3608 Caterpillar
Bow Thruster	2 X 1,700 HP / CP tunnel
Stern Thruster	1,700 HP / CP tunnel
Electronics	As per GMDSS requirements
Liquid Storage	12,690 bbls
Certification	USCG Subchapter L (OSV) and I (cargo); ABS=A1; ABS=AMS; ABS Load Line; ABS DP-2; Ice Class A1, SOLAS 2000; MARPOL 99

3608

DIESEL ENGINE TECHNICAL DATA

CATERPILLAR®

Marine RATING: Industrial 10/11/2006

ENGINE SPEED (rpm):	1000	TURBOCHARGER PART #:	194-8722
COMPRESSION RATIO:	13:1	FUEL TYPE:	Distillate
AFTERCOOLER WATER (°C):	50		
JACKET WATER OUTLET (°C):	90		
IGNITION SYSTEM:	MUI		
EXHAUST MANIFOLD:	DRY		

RATING		NOTES	LOAD	100%	75%	50%
ENGINE POWER		(2)	bkW	2710	2033	1355
ENGINE DATA						
FUEL CONSUMPTION	**(ISO 3046/1)**	**(1)**	**g/bkw-hr**	**198.7**	**197.6**	**206.2**
FUEL CONSUMPTION	(NOMINAL)	(1)	g/bkw-hr	202.5	201.4	210.2
FUEL CONSUMPTION	(90% CONFIDENCE)	(1)	g/bkw-hr	204.7	203.9	213.0
AIR FLOW (@ 25°C, 101.3 kPaa)			Nm3/min	297.6	236.5	164.7
AIR MASS FLOW			kg/hr	19921	15826	11020
COMPRESSOR OUTLET PRESSURE			kPa (abs)	280.8	199.6	110.3
COMPRESSOR OUTLET TEMPERATURE			°C	196.9	157.9	110.0
INLET MANIFOLD PRESSURE			kPa (abs)	277.0	196.9	108.8
INLET MANIFOLD TEMPERATURE			°C	45.9	43.2	42.3
TIMING		(9)	°BTDC	12.5	12.5	12.5
EXHAUST STACK TEMPERATURE			°C	370.9	354.4	371.9
Catsmoke				0.0068	0.0100	0.0178
EXHAUST GAS MASS FLOW			kg/hr	20473	16237	11304
EMISSIONS						
NOx (as NO)		(3)	g/bkW-hr	8.88	9.65	10.55
CO		(3)	g/bkW-hr	0.73	0.65	0.88
THC (molecular weight of 13.018)		(3)	g/bkW-hr	0.99	1.26	1.51
Particulates		(3)	g/bkW-hr	0.17	0.20	0.25
ENERGY BALANCE DATA						
FUEL INPUT ENERGY (LHV)	(NOMINAL)	(1)	KW	6566	4883	3390
HEAT REJ. TO JACKET WATER	(NOMINAL)	(4)	KW	539	440	343
HEAT REJ. TO ATMOSPHERE	(NOMINAL)	(5)	KW	131	98	68
HEAT REJ. TO OIL COOLER	(NOMINAL)	(6)	KW	285	251	218
HEAT REJ. TO EXH. (LHV to 25°C)	(NOMINAL)	(4)	KW	2082	1575	1186
HEAT REJ. TO EXH. (LHV to 177°C)	(NOMINAL)	(4)	KW	1632	1349	925
HEAT REJ. TO AFTERCOOLER	(NOMINAL)	(7) (8)	KW	800	479	218

CONDITIONS AND DEFINITIONS

ENGINE RATING OBTAINED AND PRESENTED IN ACCORDANCE WITH ISO 3046/1 AND SAE J1995 JAN90 STANDARD REFERENCE CONDITIONS OF 25°C, 100 KPA, 30% RELATIVE HUMIDITY AND 150M ALTITUDE AT THE STATED AFTERCOOLER WATER TEMPERATURE.
CONSULT ALTITUDE CURVES FOR APPLICATIONS ABOVE MAXIMUM RATED ALTITUDE AND/OR TEMPERATURE.
PERFORMANCE AND FUEL CONSUMPTION ARE BASED ON 35 API, 16°C FUEL HAVING A LOWER HEATING VALUE OF 42.780 KJ/KG USED AT 29°C WITH A DENSITY OF 838.9 G/LITER.

NOTES

1) FUEL CONSUMPTION TOLERANCE. ISO 3046/1 IS 0, + 5% OF FULL LOAD DATA. NOMINAL IS ± 3 % OF FULL LOAD DATA.
2) ENGINE POWER TOLERANCE IS ± 3 % OF FULL LOAD DATA.
3) EMISSION DATA SHOWN ARE NOT TO EXCEED VALUES.
4) HEAT REJECTION TO JACKET AND EXHAUST TOLERANCE IS ± 10% OF FULL LOAD DATA. (heat rate based on treated water)
5) HEAT REJECTION TO ATMOSPHERE TOLERANCE IS ±50% OF FULL LOAD DATA. (heat rate based on treated water)
6) HEAT REJECTION TO LUBE OIL TOLERANCE IS ± 20% OF FULL LOAD DATA. (heat rate based on treated water)
7) HEAT REJECTION TO AFTERCOOLER TOLERANCE IS ± 5% OF FULL LOAD DATA. (heat rate based on treated water)
8) TOTAL AFTERCOOLER HEAT = AFTERCOOLER HEAT x ACHRF (heat rate based on treated water)
9) TIMING BASED ON AFM INJECTORS.

DM5529 - 01

Kvichak (34-foot)

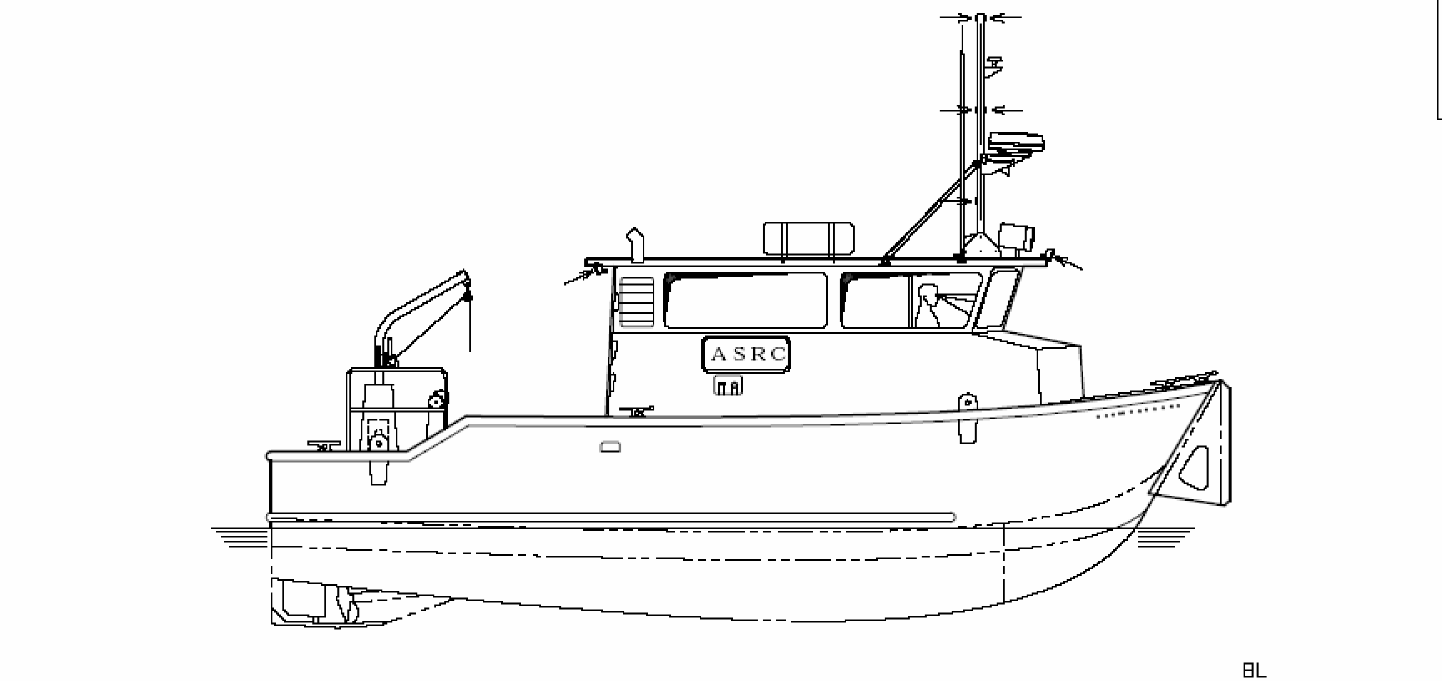
Function: Oil Spill Response

Ship Dimensions
Length: 10.4 m
Width: 3.7 m
Propulsion: (2) Cummins QSB5.9-305MCD
Reference: Vessel Specifications

Stack Parameters (propulsion engines)
Height: 3.35 m
Diameter: 0.15 m
Velocity: 32.9 m/sec
Temperature: 694 K
References: Stack height and diameter from manufacturer drawing
Velocity and temperature from manufacturer specifications

Kvichak 34-foot Oil Spill Response Work Boat

SPECIFICATIONS
LWL: ~31'-7"
LOA: ~34'-2"
BEAM: ~12'
DRAFT: ~55"
DISPLACEMENT: ~24,000LBS
FUEL: 300 GALLONS
MAX SPEED: 18KN
ENGINES: (2) CUMMINS QSB @ 305HP EA.
GEAR: TWIN-DISC V-DRIVE CONFIG. OR SIMILAR
GENSET: (1) ~8kW
EXHAUST: DRY W/ MUFFLER
COOLING: KEEL COOLED

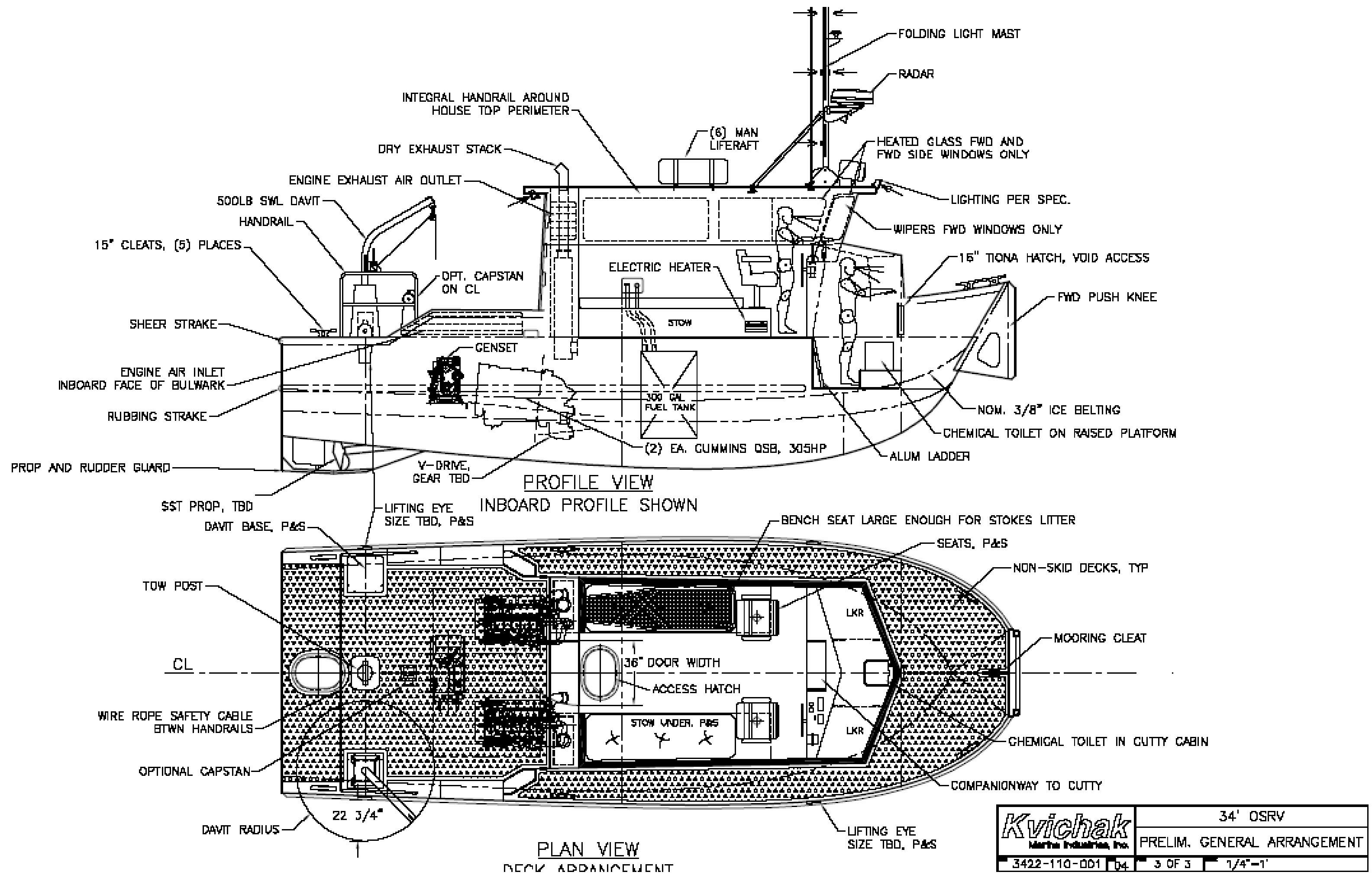


OUTBOARD PROFILE
REFER TO DETAILS ON FOLLOWING PGS

ALL DIMENSIONS FOR REFERENCE ONLY

Kvichak Marine Industries, Inc.	34' OSRV
	PRELIM. GENERAL ARRANGEMENT
3422-110-001 04	2 OF 3 1/4"=1'

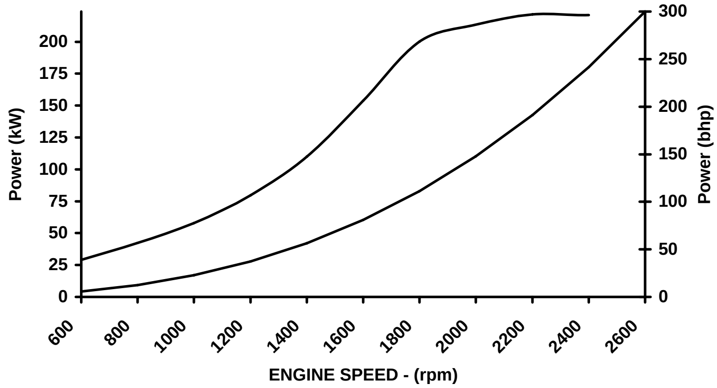
Kvichak 34-foot Oil Spill Response Work Boat
General Deck Arrangement



	CUMMINS MERCRUISER DIESEL Charleston, SC 29405 Marine Performance Curves	Basic Engine Model: **QSB5.9-305 MCD** Engine Configuration: **D403075MX03**	Curve Number: **M-91365** CPL Code: **8464** Date: **30-Oct-06**

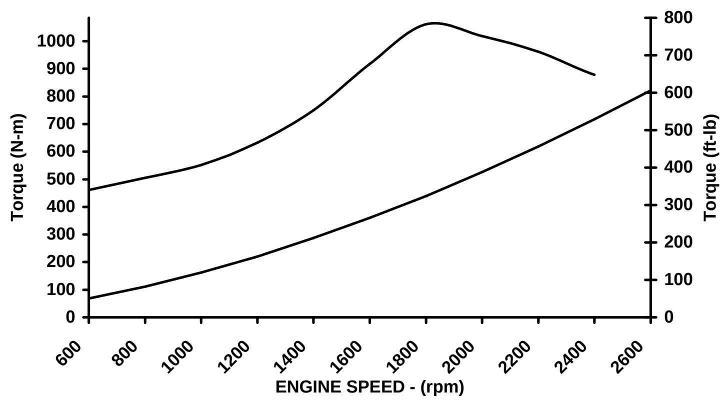
Displacement:	**5.9 liter**	**[359 in^3]**		kW [bhp, mhp] @ rpm
Bore:	**102 mm**	**[4.02 in]**	Advertised Power:	**224 [300, 305] @ 2600**
Stroke:	**120 mm**	**[4.72 in]**		
Fuel System:	**HPCR**		Aspiration:	**Turbocharged / Sea Water Aftercooled**
Cylinders:	**6**		Rating Type:	**Medium Continuous Duty**

CERTIFIED: This marine diesel engine is certified to the model year requirements of EPA Marine Tier 2 per 40 CFR 94 and conforms with the NOx requirements of the International Maritime Organization (IMO), MARPOL 73/78 Annex VI, Regulation 13 as applicable.



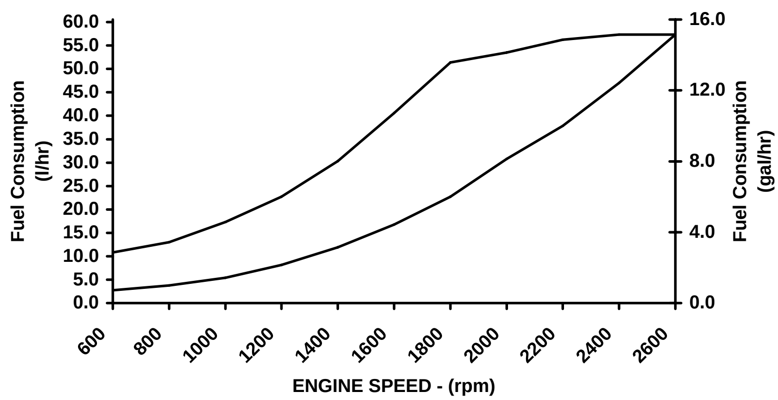
RATED POWER OUTPUT CURVE

rpm	kW	bhp
2600	224	300
2400	221	296
2200	222	297
2000	213	286
1800	200	268
1600	154	206
1400	110	147
1200	80	107
1000	58	77
800	42	57
600	29	39



FULL LOAD TORQUE CURVE

rpm	N-m	ft-lb
2600	822	606
2400	879	648
2200	961	709
2000	1018	751
1800	1062	783
1600	918	677
1400	750	553
1200	633	467
1000	552	407
800	506	373
600	461	340



FUEL CONSUMPTION - PROP CURVE

rpm	l/hr	gal/hr
2600	57.3	15.1
2400	47.0	12.4
2200	37.9	10.0
2000	30.8	8.1
1800	22.7	6.0
1600	16.8	4.4
1400	11.9	3.1
1200	8.1	2.1
1000	5.4	1.4
800	3.8	1.0
600	2.7	0.7

Rated Conditions: Ratings are based upon ISO 8665 and SAE J1228 reference conditions; air pressure of 100 kPa [29.612 in Hg], air temperature 25 deg. C [77 deg. F] and 30% relative humidity. Power is in accordance with IMCI procedure. Member NMMA.

Rated Curves (upper) represents rated power at the crankshaft for mature gross engine performance capabilities obtained and corrected in accordance with ISO 3046. Propeller Curve (lower) is based on a typical fixed propeller demand curve using a 2.7 exponent. Propeller Shaft Power is approximately 3% less than rated crankshaft power after typical reverse/reduction gear losses and may vary depending on the type of gear or propulsion system used.

Fuel Consumption is based on fuel of 35 deg. API gravity at 16 deg. C [60 deg. F0 having LHV of 42,780 kj/kg [18390 Btu/lb] and weighing 838.9 g/liter [7.001 lb/U.S. gal].

Medium Continuous Rating: This power rating is intended for continuous use in variable load applications where full power is limited to six (6) hours out of every twelve (12) hours of operation. Also, reduced power operations must be at or below 200 RPM of the maximum rated RPM. This is an ISO 3046 Fuel Stop Power Rating and is for applications that operate 3,000 hours per year or less.

James D Kahlenbeck

CHIEF ENGINEER

Marine Engine Performance Data

Curve No.: M-91365
DS-3075
DATE: 30Oct06

General Engine Data

Engine Model		QSB5.9-305 MCD
Rating Type		Med. Cont. Duty
Rated Engine Power	kW [bhp]	224 [300]
Rated Engine Speed	rpm	2600
Rated HP Production Tolerance	±%	5
Rated Engine Torque	N•m [ft•lb]	822 [606]
Peak Engine Torque @ 1800 rpm	N•m [ft•lb]	1062 [783]
Brake Mean Effective Pressure	kPa [psi]	1755 [255]
Indicated Mean Effective Pressure	kPa [psi]	N/A
Minimum Idle Speed Setting	rpm	600
Normal Idle Speed Variation	±rpm	10
High Idle Speed Range – Minimum	rpm	2665
High Idle Speed Range – Maximum	rpm	2685
Maximum Allowable Engine Speed	rpm	2685
Maximum Torque Capacity from Front of Crank[2]	N•m [ft•lb]	468 [345]
Compression Ratio		17.2:1
Piston Speed	m/sec [ft/min]	10.4 [2045]
Firing Order		1-5-3-6-2-4
Weight (Dry) Engine only - Average	kg [lb]	N.A.
Weight (Dry) Engine With Heat Exchanger System - Average	kg [lb]	612 [1350]
Weight Tolerance (Dry) Engine only - Average	kg [lb]	N.A.

Noise and Vibration

Average Noise Level – Top	(Idle)	dBA @ 1m	76
	(Rated)	dBA @ 1m	97
Average Noise Level – Right Side	(Idle)	dBA @ 1m	76
	(Rated)	dBA @ 1m	98
Average Noise Level – Left Side	(Idle)	dBA @ 1m	77
	(Rated)	dBA @ 1m	107
Average Noise Level – Front	(Idle)	dBA @ 1m	76
	(Rated)	dBA @ 1m	98

Fuel System[1]

Average Fuel Consumption – ISO 8178 E3Standard Test Cycle	l/hr [gal/hr]	38.7 [10.2]
Fuel Consumption @ Rated Speed	l/hr [gal/hr]	57 [15]
Approximate Fuel Flow to Pump	l/hr [gal/hr]	189 [50]
Maximum Allowable Fuel Supply to Pump Temperature	°C [°F]	60 [140]
Approximate Fuel Flow Return to Tank	l/hr [gal/hr]	132 [35]
Approximate Fuel Return to Tank Temperature	°C [°F]	66 [150]
Maximum Heat Rejection to Drain Fuel[5]	kW [Btu/min]	2 [99]
Fuel Transfer Pump Pressure Range	kPa [psi]	76 [11]
Fuel Rail Pressure – Gauge	kPa [psi]	N.A.
Fuel Rail Pressure – INSITE	kPa [psi]	135,999 [19,725]

Air System[1]

Intake Manifold Pressure	kPa [in Hg]	172 [51]
Intake Air Flow	l/sec [cfm]	278 [58]
Heat Rejection to Ambient	kW [Btu/min]	32 [1810]
Maximum Air Cleaner Inlet Temperature Rise Over Ambient	°C [°F]	17 [30]

Exhaust System[1]

Exhaust Gas Flow	l/sec [cfm]	600 [1272]
Exhaust Gas Temperature – Turbine Out	°C [°F]	421 [789]
Exhaust Gas Temperature – Manifold	°C [°F]	559 [1038]

TBD = To Be Decided **N/A = Not Applicable** **N.A. = Not Available**

[1]All Data at Rated Conditions
[2]Consult Installation Direction Booklet for Limitations
[3]Heat rejection values are based on 50% water/ 50% ethylene glycol mix and do NOT include fouling factors. If sourcing your own cooler, a service fouling factor should be applied according to the cooler manufacturer's recommendation.
[4]Consult option notes for flow specifications of optional Cummins seawater pumps, if applicable.
[5]May not be at rated load and speed. Maximum heat rejection may occur at other than rated conditions.

CUMMINS ENGINE COMPANY, INC.
COLUMBUS, INDIANA

All Data is Subject to Change Without Notice - Consult the following Cummins intranet site for most recent data: http://www.cummins.com

Marine Engine Performance Data

Curve No.: M-91365
DS-3075
DATE: 30Oct06

Emissions (in accordance with ISO 8178 Cycle E3)

NOx (Oxides of Nitrogen)	g/kw·hr [g/hp·hr]	6.227 [4.644]
HC (Hydrocarbons)	g/kw·hr [g/hp·hr]	0.104 [0.078]
CO (Carbon Monoxide)	g/kw·hr [g/hp·hr]	0.208 [0.155]
PM (Particulate Matter)	g/kw·hr [g/hp·hr]	0.103 [0.077]

Cooling System[1]

Sea Water Aftercooled Engine (SWAC)		
Sea Water Pump Specifications	MAB 0.08.17-07/16/2001	
Pressure Cap Rating (With Heat Exchanger Option)	kPa [psi]	103 [15]
Standard Thermostat Operating Range Start to Open	°C [°F]	74 [165]
Full Open	°C [°F]	85 [185]
Engines with Single Loop Keel Cooling		
Coolant Flow to Cooler (with blocked open thermostat)	l/min [gal/min]	136 [36]
LTA Thermostat Operating Range Start to Open	°C [°F]	66 [150]
Full Open	°C [°F]	80 [175]
Heat Rejection to LTA Coolant[3]	kW [Btu/min]	183 [10420]
Maximum LTA Coolant Return Temperature	°C [°F]	54 [130]

TBD = To Be Decided **N/A = Not Applicable** **N.A. = Not Available**

1All Data at Rated Conditions
2Consult Installation Direction Booklet for Limitations
3Heat rejection values are based on 50% water/ 50% ethylene glycol mix and do NOT include fouling factors. If sourcing your own cooler, a service fouling factor should be applied according to the cooler manufacturer's recommendation.
4Consult option notes for flow specifications of optional Cummins seawater pumps, if applicable.
5May not be at rated load and speed. Maximum heat rejection may occur at other than rated conditions.

CUMMINS ENGINE COMPANY, INC.
COLUMBUS, INDIANA

All Data is Subject to Change Without Notice - Consult the following Cummins intranet site for most recent data: http://www.cummins.com

Vladimir Ignatjuk

Function: Primary / Secondary Icebreaker

Ship Dimensions
Length: 88.0 m
Width: 17.5 m
Propulsion: (4) Stork Werkspoor 8TM410 (4,325 kW each)
Reference: Vessel Specifications

Stack Parameters (propulsion engines)
Height: 24.38 m
Diameter: 0.79 m
Velocity: 33.2 m/sec @ 80% load
Temperature: 668 K @ 80% load
Reference: Stack test - 5/20/2007

AHTS M/V " Vladimir Ignatjuk " (ex. Artic Kalvik)

Design	Canadian
Classification	Lloyd's Register of Shipping + 100 A1 Icebreaker Tug + LMC Lloyd's Register of Shipping 100 A1 LMC, icebreaking tow, ice class - 1A Super
Built / Delivered	

DIMENSIONS				
Length Over All (LOA)	88.02	m	ft	
Length between p.p		m	ft	
Breath Moulded	17.51	m	ft	
Depth to main deck		m	ft	
Draught design	8,3	m	ft	
Freeboard design		m	ft	
TONNAGE				
Dead weight (DWT)	2113 Metric tonnes			
Light Ship	Metric tonnes			
Gross tonnage (GRT)	Metric tonnes			
Net tonnage (NET)	Metric tonnes			
CAPACITIES				
Dry bulk		M^3	ft^3	In four tanks
Potable water		m^3		
Drill Water - Ballast		M^3		
Oil / water based mud		m^3		Specific Gravity 2.5
Base Oil		m^3		
Fuel Oil		m^3		Marine gas oil
Urea		m^3		

Particulars believed to be correct, without guarantee

Clear Deck Area	m^2	
Deck load	tonnes	
	m^3	

DISCHARGE RATES

Dry Bulk

Pot Water

Drill water / Ballast

Brine

Oil Based Mud

Base Oil

Fuel Oil (Diesel)

Discharge Stations

Discharge Lines

Tank Cleaning

Flow Meters

PROPULSION

Main Engines	4 x 5800 BHP. Two-shaft diesel-reduction gear engine with 4 main engines and variable-pitch propeller.GD type - 8TM410, Stork Werkspoor Diesel
Thrusters	
Propellers	
Rudders	

BOLLARD PULL

Bollard pull	202 tonnes BP continous (DnV certified) approx. 210 t max pull

SPEED / CONSUMPTION

16 knots	Approx 42.5 tonnes /day @ 6 m. draught
12 knots	Approx 15.6 tonnes /day @ 6 m. draught
10 knots	Approx 10 tonnes /day @ 6 m. draught

TOWING ANCHORHANDLING EQUIPMENT

AHT Winch	Brattvaag towing/anchorhandling winch 400 ts pull / 550 ts brake holding cap
AHT Drum	One of 1,400 mm dia. x 3,750 dia x (1,250 mm + 1,250 mm) length
Wire Capacity	2 x 1,900 m of 77 mm wire or 2 x 1,650 m of 83 mm wire
AH Drum	One of 1,400 mm dia. x 3,750 mm dia. x 3,000 mm length
Wire Capacity	4,100 m of 83 mm wire
Winch Control	TOWCON 2000 Aut. Control with printer
Pennant Reels/Caps	One off 2 x 1,500 m of 77 mm wire or 2 x 1,300 m of 83 mm wire capacity One off 3,400 m of 77 mm wire or 1 x 3,100 m of 83 mm wire capacity

Particulars believed to be correct, without guarantee

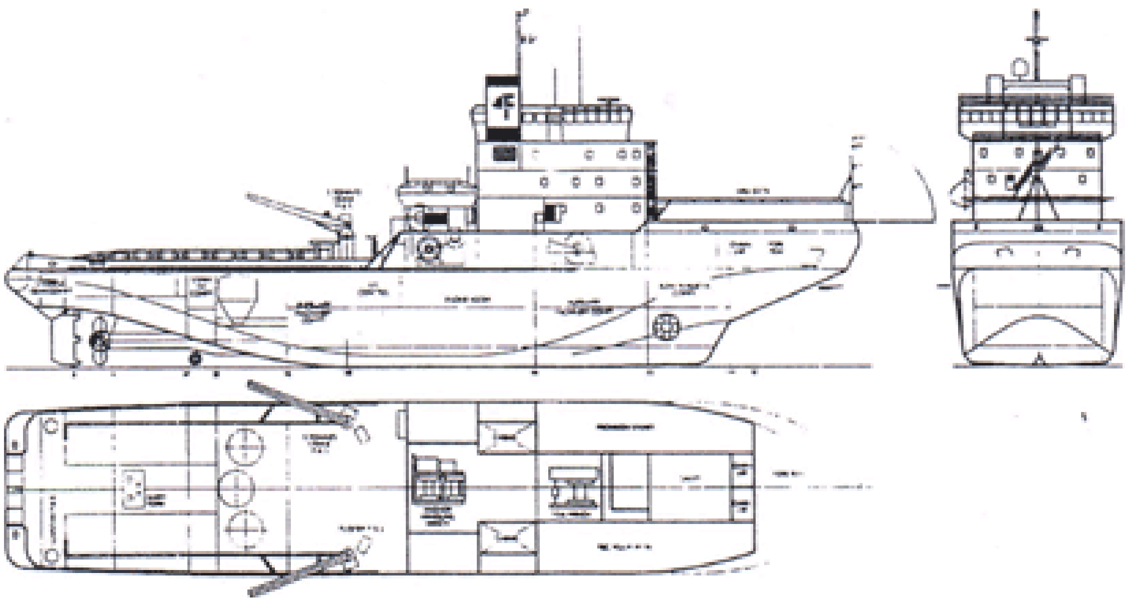
Cable Lifters	2 x 76 mm and 2 x 84 mm onboard
Chain Lockers	2 x 125 m^3 / giving abt 2 x 6,000 ft of 3 inch chain
Shark Jaws	2 pairs of Karm Forks arranged for chain up to 165 mm dia / 750 ts SWL Inserts for handling 65, 75, 85, 100, and 120 mm dia. wire/chain
Stern Roller	One of 3,5 m dia. x 6.0 m length – SWL 500 ts
Guide Pins	2 pairs of Karm Fork Hydraulic pins – SWL 170 ts

DECK EQUIPMENT	
Capstans	2 x 15 ts pull
Tugger Winches	2 x 15 ts pull
Smit Brackets	One bracket on B Deck FW – SWL 250 ts
Cranes	1 hydraulic crane on forep cargo deck giving 6 / 12 ts at 20/10 m arm (360 degr
	1 telescopic crane on aft cargo deck giving 1.5 / 3 ts at 15/10 m arm (360 degr)
	1 hydraulic crane on fore-castle deck for stores etc
Windlass	1 hydraulic windlass / mooring winch. Two de-clutchable drums 46 mm K3 chain

Accommodation
Accommodation for a total of 23 persons, including crew
All accommodation equipped with air-condition and humidification facilities.

Misc.
We would like to highlight the exceptional good maneuverability of the vessel. Also please note the environmental bonus using "Tor Viking" due to her exceptional low noise level, and the installed Exhaust Gas Treatment Systems (Catalyst), effectively reducing the NOx levels. "Tor Viking" is also equipped with diesel overflow tank with alarm system. The vessels design, and her possibility for running 2 engines, ("father/son") gives a very favourable fuel consumption.

DynPos 2 – Kongsberg Simrad SDP21 system will be installed during winter 2002/03



Particulars believed to be correct, without guarantee

Table 2.1.1
Summary of Average NO_x Results

Main Propulsion Engine (Main Engine #3)
Unit VI-3, Source Group B1
May 20, 2007

Shell Offshore, Inc.
Kulluk Drilling Unit (Kulluk)
Norway

Method	Pollutant	Emission Unit	Run #			Average
LOAD CONDITION – 80%			7	8	9	
Power Produced	---	kW/hr	3000	3000	3000	**3000**
Method 7E	NO_x	ppm	822.0	815.5	804.5	**814.0**
	NO_x	lb/hr	85.2	83.9	81.6	**83.6**
	NO_x	lb/MMBtu	2.448	2.429	2.396	**2.424**
	NO_x	lb/kW-hr	0.0284	0.0289	0.0389	**0.0321**
LOAD CONDITION – 57%			4	5	6	
Power Produced	---	kW/hr	2000	2000	2000	**2000**
Method 7E	NO_x	ppm	797.4	833.6	811.6	**814.2**
	NO_x	lb/hr	65.2	69.4	70.4	**68.4**
	NO_x	lb/MMBtu	2.650	2.693	2.659	**2.667**
	NO_x	lb/kW-hr	0.0326	0.0347	0.0352	**0.0342**
LOAD CONDITION – 35%			1	2	3	
Power Produced	---	kW/hr	1000	1000	1000	**1000**
Method 7E	NO_x	ppm	486.5	489.9	524.8	**500.3**
	NO_x	lb/hr	29.4	28.7	30.6	**29.6**
	NO_x	lb/MMBtu	1.957	1.971	2.111	**2.013**
	NO_x	lb/kW-hr	0.0294	0.0287	0.0306	**0.0296**

TRC Environmental Corp.

EMISSION MEASUREMENTS DEPARTMENT

19874 141st Place N.E.
Woodinville, WA 98072
Phone: (425) 489-1938
Fax: (425) 489-9564

CLIENT:	Shell Offshore, Inc. - Norway	DATES:	5/20/2007
LOCATION:	Vladimir Ignatjuk	PROJECT NO.:	150614
UNIT:	Main Engine #3	PERSONNEL:	MM/PJC/MLE
CONDITION:	35% Load		

Data Input Sheet

The table below contains the results of testing and calculations performed by TRC on the date(s) listed.

Moisture & Airflow

Parameter	SYMBOL	UNITS	DATA			
Test Number			Run 1	Run 2	Run 3	
Test Date			5/20/2007	5/20/2007	5/20/2007	
Method 4 Start Time			0550	0702	0812	
Method 4 Stop Time			0650	0802	0912	**3-RUN AVG.**
Stack Diameter	ds	inches	31.0	31.0	31.0	
Barometric Pressure at Sampling Location	Pbar	in. Hg	30.10	30.10	30.10	30.10
Stack Static Pressure	Pg	in. H_2O	0.25	0.25	0.25	0.25
Pitot Coefficient	cp	none	0.84	0.84	0.84	
Meter Calibration Factor	Y	none	0.976	0.976	0.976	
	DH@	none	1.678	1.678	1.678	
Stack Gas Oxygen Content	O_2	%	15.2	15.2	15.2	15.2
Stack Gas Carbon Dioxide Content	CO_2	%	4.5	4.5	4.5	4.5
Net Moisture Gain (Impingers w/SiGel)	Ww	grams	25.3	25.3	25.3	25.3
Average Stack Temperature	ts	deg F	582.5	586.2	590.6	586.4
Average Meter Temperature	tm	deg F	80.6	90.9	97.5	89.6
Avg Delta H	dH	in. H_2O	1.00	1.00	1.00	1.00
Average Square Root Delta H	ASR dH	in. H_2O	1.000	1.000	1.000	1.000
Avg Velocity Head	dP	in. H_2O	0.48	0.46	0.46	0.47
Average Square Root Delta P	ASR dP	in. H_2O	0.693	0.675	0.672	0.680
Gas Sample Volume	Vm	cu. ft.	37.220	35.133	35.787	36.047
Total Sampling Time	min	minutes	60	60	60	

TRC Environmental Corp. EMISSION MEASUREMENTS DEPARTMENT
19874 141st Place N.E.
Woodinville, WA 98072
Phone: (425) 489-1938
Fax: (425) 489-9564

CLIENT:	Shell Offshore, Inc. - Norway	DATES:	5/20/2007
LOCATION:	Vladimir Ignatjuk	PROJECT NO.:	150614
UNIT:	Main Engine #3	PERSONNEL:	MM/PJC/MLE
CONDITION:	35% Load		

Calculation Sheet

The table below contains the results of testing and calculations performed by TRC on the date(s) listed.

Moisture & Airflow

Parameter	SYMBOL	UNITS	DATA			
Test Number			Run 1	Run 2	Run 3	
Test Date			5/20/2007	5/20/2007	5/20/2007	
Method 4 Start Time:			0550	0702	0812	
Method 4 Stop Time:			0650	0802	0912	
Calculated Data						**3-RUN AVG.**
Stack Area,As=3.14159*((Ds/12)/2)^2	As	sq.ft.	5.24	5.24	5.24	5.24
Avg Stack Temperature, Ts=ts+460	Ts	deg R	1042.5	1046.2	1050.6	1046.4
Meter Pressure, Pm=Pb+Dh/13.6	Pm	in. Hg	30.17	30.17	30.17	30.17
Avg Meter Temperature, Tm=tm+460	Tm	deg R	540.6	550.9	557.5	549.6
Gas Sample Volume at Standard Conditions,	Vm(std)	cu. ft.	35.783	33.145	33.360	34.096
Vm(std)= 528/29.92*Y*Vm*Pm/Tm		cu. m.	1.013	0.938	0.944	0.965
Net Moisture Gain (Impingers w/SiGel)	Ww	grams	25.3	25.3	25.3	25.3
Volume of Water Vapor, Vw(std)= 0.04715*Wlc	Vw(std)	cu. ft.	1.194	1.194	1.194	1.194
Moisture Fraction, Bws = Vw(Std)/(Vm(Std)+Vw(Std))*100	Bws	%	3.23%	3.48%	3.46%	3.39%
Dry Stack Gas Molecular Weight, Md = (0.32*O2)+(0.44*CO2)+(0.28*(100-(O2+CO2)))	Mwd	g/g-mole	29.33	29.33	29.33	29.33
Wet Stack Gas Molecular Weight Mw = Md* (1-Bws)+(18*(Bws))	Mws	g/g-mole	28.96	28.93	28.94	28.94
Absolute Stack Pressure, Ps = Pbar + Pg/13.6	Ps	in. Hg.	30.12	30.12	30.12	30.12
Stack Gas Velocity Vs= 85.49*Cp*ASRdP*((Ts)/((Ps)*(Mw)))^0.5	Vs	ft/sec	54.40	53.08	53.00	53.49
Vsm = 0.3048* Vs	Vsm	m/sec	16.58	16.18	16.15	16.30
Actual Stack Gas Flow Rate, Qa = 60*Vs*As	Qa	acf/min	17,109	16,694	16,666	16,823
Stack Gas Flow Rate (STP), Qsw = 528/29.92 * Qa * (Ps/Ts)	Qsw	scf/min	8,722	8,482	8,432	8,545
Dry Stack Gas Flow Rate (Dry, STP),	Qsd	dscf/min	8,440.6	8,186.5	8,140.2	8,255.8
Qsd = 528/29.92 * Qa * (1-Bws)* (Ps/Ts)		dscm/min	239.0	231.8	230.4	233.7
Meter Calibration (Alternate Method) Yqa=Min/Vm*((0.0319*Tm*29)/(DH@*(Pbar+dH/13.6)*Md))^0.5	Yqa	none	0.9355	1.0005	0.9881	0.9747
Meter Quality Assurance/Quality Check =100*(Y-Yqa)/Y		% Diff	4.1%	-2.5%	-1.2%	0.1%

Sampling Data Summary

Parameter	SYMBOL	UNITS	Run 1	Run 2	Run 3	3-RUN AVG.
Total Sampling Time	min	minutes	60	60	60	60
Stack Gas Oxygen Content	O_2	%	15.2	15.2	15.2	15.2
Stack Gas Carbon Dioxide Content	CO_2	%	4.5	4.5	4.5	4.5
Gas Sample Volume at Standard Conditions,	Vm(std)	cu. ft.	35.783	33.145	33.360	34.096
		cu. m.	1.013	0.938	0.944	0.965
Dry Stack Gas Flow Rate (Dry, STP),	Qsd	dscf/min	8,440.6	8,186.5	8,140.2	8,255.8
		dscm/min	239.0	231.8	230.4	233.7

TRC Environmental Corp. EMISSION MEASUREMENTS DEPARTMENT

19874 141st Place N.E.
Woodinville, WA 98072
Phone: (425) 489-1938
Fax: (425) 489-9564

CLIENT:	Shell Offshore, Inc. - Norway	DATES:	5/20/2007
LOCATION:	Vladimir Ignatjuk	PROJECT NO.:	150614
UNIT:	Main Engine #3	PERSONNEL:	MM/PJC/JT
CONDITION:	57% Load		

Data Input Sheet

The table below contains the results of testing and calculations performed by TRC on the date(s) listed.

Moisture & Airflow

Parameter	SYMBOL	UNITS	DATA			
Test Number			Run 4	Run 5	Run 6	
Test Date			5/20/2007	5/20/2007	5/20/2007	
Method 4 Start Time			0936	1052	1216	
Method 4 Stop Time			1036	1152	1316	3-RUN AVG.
Stack Diameter	ds	inches	31.0	31.0	31.0	
Barometric Pressure at Sampling Location	Pbar	in. Hg	30.10	30.10	30.10	30.10
Stack Static Pressure	Pg	in. H_2O	0.35	0.35	0.35	0.35
Pitot Coefficient	cp	none	0.84	0.84	0.84	
Meter Calibration Factor	Y	none	0.976	0.976	0.976	
	DH@	none	1.678	1.678	1.678	
Stack Gas Oxygen Content	O_2	%	14.0	13.8	13.9	13.9
Stack Gas Carbon Dioxide Content	CO_2	%	5.5	5.6	5.5	5.5
Net Moisture Gain (Impingers w/SiGel)	Ww	grams	39.2	39.2	39.2	39.2
Average Stack Temperature	ts	deg F	687.8	689.9	689.5	689.1
Average Meter Temperature	tm	deg F	96.4	98.4	94.7	96.5
Avg Delta H	dH	in. H_2O	1.00	1.00	1.00	1.00
Average Square Root Delta H	ASR dH	in. H_2O	1.000	1.000	1.000	1.000
Avg Velocity Head	dP	in. H_2O	1.02	1.05	1.15	1.07
Average Square Root Delta P	ASR dP	in. H_2O	1.002	1.020	1.063	1.029
Gas Sample Volume	Vm	cu. ft.	36.211	37.444	36.704	36.786
Total Sampling Time	min	minutes	60	60	60	

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CLIENT:	Shell Offshore, Inc. - Norway	DATES:	5/20/2007
LOCATION:	Vladimir Ignatjuk	PROJECT NO.:	150614
UNIT:	Main Engine #3	PERSONNEL:	MM/PJC/JT
CONDITION:	57% Load		

Calculation Sheet

The table below contains the results of testing and calculations performed by TRC on the date(s) listed.

Moisture & Airflow

Parameter	SYMBOL	UNITS	DATA			
Test Number			Run 4	Run 5	Run 6	
Test Date			5/20/2007	5/20/2007	5/20/2007	
Method 4 Start Time:			0936	1052	1216	
Method 4 Stop Time:			1036	1152	1316	
Calculated Data						**3-RUN AVG.**
Stack Area,As=3.14159*((Ds/12)/2)^2	As	sq.ft.	5.24	5.24	5.24	5.24
Avg Stack Temperature, Ts=ts+460	Ts	deg R	1147.8	1149.9	1149.5	1149.1
Meter Pressure, Pm=Pb+Dh/13.6	Pm	in. Hg	30.17	30.17	30.17	30.17
Avg Meter Temperature, Tm=tm+460	Tm	deg R	556.4	558.4	554.7	556.5
Gas Sample Volume at Standard Conditions,	Vm(std)	cu. ft.	33.820	34.851	34.387	34.353
Vm(std)= 528/29.92*Y*Vm*Pm/Tm		cu. m.	0.957	0.987	0.973	0.973
Net Moisture Gain (impingers w/SiGel)	Ww	grams	39.2	39.2	39.2	39.2
Volume of Water Vapor, Vw(std)= 0.04715*Wlc	Vw(std)	cu. ft.	1.847	1.847	1.847	1.847
Moisture Fraction, Bws = Vw(Std)/(Vm(Std)+Vw(Std))*100	Bws	%	5.18%	5.03%	5.10%	5.10%
Dry Stack Gas Molecular Weight, Md = (0.32*O2)+(0.44*CO2)+(0.28*(100-(O2+CO2)))	Mwd	g/g-mole	29.44	29.45	29.44	29.44
Wet Stack Gas Molecular Weight Mw = Md* (1-Bws)+(18*(Bws))	Mws	g/g-mole	28.85	28.87	28.85	28.86
Absolute Stack Pressure, Ps = Pbar + Pg/13.6	Ps	in. Hg.	30.13	30.13	30.13	30.13
Stack Gas Velocity Vs= 85.49*Cp*ASRdP*((Ts)/((Ps)*(Mw)))^0.5	Vs	ft/sec	82.69	84.25	87.81	84.92
Vsm = 0.3048* Vs	Vsm	m/sec	25.20	25.68	26.76	25.88
Actual Stack Gas Flow Rate, Qa = 60*Vs*As	Qa	acf/min	26,004	26,497	27,615	26,706
Stack Gas Flow Rate (STP), Qsw = 528/29.92 * Qa * (Ps/Ts)	Qsw	scf/min	12,044	12,250	12,772	12,355
Dry Stack Gas Flow Rate (Dry, STP),	Qsd	dscf/min	11,420.4	11,633.7	12,120.6	11,724.9
Qsd = 528/29.92 * Qa * (1-Bws)* (Ps/Ts)		dscm/min	323.3	329.4	343.1	331.9
Meter Calibration (Alternate Method) Yqa=Min/Vm*((0.0319*Tm*29)/(DH@*(Pbar+dH/13.6)*Md))^0.5	Yqa	none	0.9737	0.9432	0.9592	0.9587
Meter Quality Assurance/Quality Check =100*(Y-Yqa)/Y		% Diff	0.2%	3.4%	1.7%	1.8%

Sampling Data Summary

Parameter	SYMBOL	UNITS	Run 4	Run 5	Run 6	3-RUN AVG.
Total Sampling Time	min	minutes	60	60	60	60
Stack Gas Oxygen Content	O_2	%	14.0	13.8	13.9	13.9
Stack Gas Carbon Dioxide Content	CO_2	%	5.5	5.6	5.5	5.5
Gas Sample Volume at Standard Conditions,	Vm(std)	cu. ft.	33.820	34.851	34.387	34.353
		cu. m.	0.957	0.987	0.973	0.973
Dry Stack Gas Flow Rate (Dry, STP),	Qsd	dscf/min	11,420.4	11,633.7	12,120.6	11,724.9
		dscm/min	323.3	329.4	343.1	331.9

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CLIENT:	Shell Offshore, Inc. - Norway	DATES:	5/20/2007
LOCATION:	Vladimir Ignatjuk	PROJECT NO.:	150614
UNIT:	Main Engine #3	PERSONNEL:	MM/PJC/TJ/GWH
CONDITION:	80% Load		

Data Input Sheet

The table below contains the results of testing and calculations performed by TRC on the date(s) listed.

Moisture & Airflow

Parameter	SYMBOL	UNITS	DATA			
Test Number			Run 7	Run 8	Run 9	
Test Date			5/20/2007	5/20/2007	5/20/2007	
Method 4 Start Time			1352	1508	1620	
Method 4 Stop Time			1452	1608	1720	**3-RUN AVG.**
Stack Diameter	ds	inches	31.0	31.0	31.0	
Barometric Pressure at Sampling Location	Pbar	in. Hg	30.10	30.10	30.10	30.10
Stack Static Pressure	Pg	in. H_2O	0.50	0.50	0.50	0.50
Pitot Coefficient	cp	none	0.84	0.84	0.84	
Meter Calibration Factor	Y	none	0.976	0.976	0.976	
	DH@	none	1.678	1.678	1.678	
Stack Gas Oxygen Content	O_2	%	13.2	13.2	13.2	13.2
Stack Gas Carbon Dioxide Content	CO_2	%	6.1	6.1	6.1	6.1
Net Moisture Gain (Impingers w/SiGel)	Ww	grams	40.2	40.2	40.2	40.2
Average Stack Temperature	ts	deg F	741.2	742.6	741.9	741.9
Average Meter Temperature	tm	deg F	93.6	95.1	94.9	94.5
Avg Delta H	dH	in. H_2O	1.00	1.00	1.00	1.00
Average Square Root Delta H	ASR dH	in. H_2O	1.000	1.000	1.000	1.000
Avg Velocity Head	dP	in. H_2O	1.71	1.68	1.64	1.68
Average Square Root Delta P	ASR dP	in. H_2O	1.303	1.292	1.273	1.289
Gas Sample Volume	Vm	cu. ft.	34.995	36.878	36.596	36.156
Total Sampling Time	min	minutes	60	60	60	

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CLIENT:	Shell Offshore, Inc. - Norway	DATES:	5/20/2007
LOCATION:	Vladimir Ignatjuk	PROJECT NO.:	150614
UNIT:	Main Engine #3	PERSONNEL:	IM/PJC/TJ/GWH
CONDITION:	80% Load		

Calculation Sheet

The table below contains the results of testing and calculations performed by TRC on the date(s) listed.

Moisture & Airflow

Parameter	SYMBOL	UNITS	DATA			
Test Number			Run 7	Run 8	Run 9	
Test Date			5/20/2007	5/20/2007	5/20/2007	
Method 4 Start Time:			1352	1508	1620	
Method 4 Stop Time:			1452	1608	1720	
Calculated Data						**3-RUN AVG.**
Stack Area,As=3.14159*((Ds/12)/2)^2	As	sq.ft.	5.24	5.24	5.24	5.24
Avg Stack Temperature, Ts=ts+460	Ts	deg R	1201.2	1202.6	1201.9	1201.9
Meter Pressure, Pm=Pb+Dh/13.6	Pm	in. Hg	30.17	30.17	30.17	30.17
Avg Meter Temperature, Tm=tm+460	Tm	deg R	553.6	555.1	554.9	554.5
Gas Sample Volume at Standard Conditions,	Vm(std)	cu. ft.	32.853	34.528	34.277	33.886
Vm(std)= 528/29.92*Y*Vm*Pm/Tm		cu. m.	0.930	0.977	0.970	0.959
Net Moisture Gain (Impingers w/SiGel)	Ww	grams	40.2	40.2	40.2	40.2
Volume of Water Vapor, Vw(std)= 0.04715*Wlc	Vw(std)	cu. ft.	1.894	1.894	1.894	1.894
Moisture Fraction, Bws = Vw(Std)/(Vm(Std)+Vw(Std))*100	Bws	%	5.45%	5.20%	5.24%	5.30%
Dry Stack Gas Molecular Weight, Md = (0.32*O2)+(0.44*CO2)+(0.28*(100-(O2+CO2))	Mwd	g/g-mole	29.50	29.50	29.50	29.50
Wet Stack Gas Molecular Weight Mw = Md* (1-Bws)+(18*(Bws))	Mws	g/g-mole	28.88	28.91	28.90	28.89
Absolute Stack Pressure, Ps = Pbar + Pg/13.6	Ps	in. Hg.	30.14	30.14	30.14	30.14
Stack Gas Velocity Vs= 85.49*Cp*ASRdP*((Ts)/((Ps)*(Mw)))^0.5	Vs	ft/sec	109.92	108.98	107.42	108.77
Vsm = 0.3048* Vs	Vsm	m/sec	33.50	33.22	32.74	33.15
Actual Stack Gas Flow Rate, Qa = 60*Vs*As	Qa	acf/min	34,570	34,272	33,783	34,208
Stack Gas Flow Rate (STP), Qsw = 528/29.92 * Qa * (Ps/Ts)	Qsw	scf/min	15,306	15,156	14,948	15,137
Dry Stack Gas Flow Rate (Dry, STP),	Qsd	dscf/min	14,471.4	14,367.9	14,165.7	14,335.0
Qsd = 528/29.92 * Qa * (1-Bws)* (Ps/Ts)		dscm/min	409.7	406.8	401.0	405.8
Meter Calibration (Alternate Method) Yqa=Min/Vm*((0.0319*Tm*29)/(DH@*(Pbar+dH/13.6)*Md))^0.5	Yqa	none	1.0039	0.9539	0.9611	0.9729
Meter Quality Assurance/Quality Check =100*(Y-Yqa)/Y		% Diff	-2.9%	2.3%	1.5%	0.3%

Sampling Data Summary

Parameter	SYMBOL	UNITS	Run 7	Run 8	Run 9	3-RUN AVG.
Total Sampling Time	min	minutes	60	60	60	60
Stack Gas Oxygen Content	O_2	%	13.2	13.2	13.2	13.2
Stack Gas Carbon Dioxide Content	CO_2	%	6.1	6.1	6.1	6.1
Gas Sample Volume at Standard Conditions,	Vm(std)	cu. ft.	32.853	34.528	34.277	33.886
		cu. m.	0.930	0.977	0.970	0.959
Dry Stack Gas Flow Rate (Dry, STP),	Qsd	dscf/min	14,471.4	14,367.9	14,165.7	14,335.0
		dscm/min	409.7	406.8	401.0	405.8

Kapitan Dranitsyn

Function: Primary Icebreaker

Ship Dimensions
Length: 132.4 m
Width: 26.5 m
Propulsion: (6) Sulzer 9ZL40/48 (3,087 kW each)
Reference: Vessel Specifications

Stack Parameters (propulsion engines)
Height: 35.05 m
Diameter: 0.76 m
Velocity: 43.7 m/sec @ 80% load
Temperature: 594 K @ 80% load
Reference: Stack test - 5/21/2007

Joel Firebaugh

From: Wayne Wooster [wwooster@airsci.com]
Sent: Thursday, August 31, 2006 7:39 PM
To: 'Tim Martin'; Daniel Young
Subject: Kapitan Dranitsyn description
Attachments: header.htm

Wayne E. Wooster
Associate Air Quality Engineer
Air Sciences Inc.
421 SW 6th Ave Ste 1400
Portland, OR 97204
1301 Washington Ave Ste 200
Golden, CO 80401-1915
Direct Phone: 503-525-9394 ext. 15
Company Fax: 503-525-9412
Cell Phone: 971-998-3144
Email: wwooster@airsci.com
Efax: 971-285-9043
Company Web Site: www.airsci.com

From: keith.craik@shell.com [mailto:keith.craik@shell.com]
Sent: Thursday, August 31, 2006 4:17 AM
To: wwooster@airsci.com
Subject: FW: tc_description_2.doc

Wayne,
Kapitan Dranitsyn info
-----Original Message-----
From: Muddusetti, Suman SIEP-EPT-PDF
Sent: Wednesday, June 28, 2006 7:42 AM
To: Craik, Keith KM SIEP-EPT-PDS
Subject: tc_description_2.doc

Description of the Vessel

"KAPITAN DRANITSYN"

1 General

a) Owner Name: JS Murmansk Shipping Company, Russia
b) Owner Address: 15, Kominterna street, 183038, Murmansk, Russia
c) Operator Name: as above
d) Operator Address: as above
e) Vessel Name : “Kapitan Dranitsyn”
f) Builder: "Wartsila" shipyard, Helsinki, Finland
g) Where Built:
h) Year Built: 1980
i) Type: Icebreaker/passenger
j) Classification: Icebreaker (КМ ЛЛ7), passenger class
k) Classification Society: RUSSIAN MARITIME REGISTER OF SHIPPING
l) Flag : RUSSIA
m) Date of next scheduled docking: may 2006

2 Performance

a) Certified Bollard Pull: 120 tn
b) Maximum Speed (non-towing in fair weather): about 18,5 knt
c) Fuel Consumption at Maximum Speed: IFO30- 103 mt + MGO- 7 mt
d) Service Speed on two engines (non-towing in fair weather): abt 12,0 knt
e) Fuel Consumption at Service Speed: IFO30- 28,0 mt + MGO- 7 mt
f) Fuel Consumption for 1 engine (at 70% load): n/a
g) Fuel Consumption at port: IFO30- 5 mt + MGO- 3 mt
h) Approx. Towing/Heavy ice condition (engine power at 100%): 110 mt + 7 mt
i) Types & Grades of fuel used: IFO30/RMA10 and MDO/DMB All according to ISO 8217 1996(E). To ensure work of ME and ADG when starting and stopping and to ensure work of emergency DG aboard motor vessel the supplies of diesel oil (gasoil DMA) are provided in amount of 5% of fuel oil demand without of daily consumption extension.
j) Maximum Endurance (days): 29
k) LOA: 132,4 m
l) Beam: 26,5 m
m) Draft: 8,5 m
n) Keel to Masthead: 48,7 m
o) Masthead Height: n/a
p) Deadweight: 4515 t
q) Liquid Cargo Capacity: none
r) Fuel Delivery Capacity: 2950 mt IFO30/ 600 mt MDO
s) Cargo Pump Type: Nil
t) Cargo Pumping Rate & Pressure: Nil
u) Fuel Pump Type: ACF 100 – 3 N3F x 2
v) Fuel Pumping Rate & Pressure: 72m³ / 3-4 kg/cm^2
w) Fresh Water Capacity: 466 mt
x) Fresh Water Pump Type: KLHP - 70
y) Fresh Water Pumping Rate & Pressure: 50 m³/2,5 kg/cm^2
z) Oil Spill Recovery Tank Capacity: 81.00 m³ + 352 m³ + 78,9 m³
aa) Cargo Deck Area (aft): Helicopter hangar with L/B/H 11.5/5.5/4.0 mtrs
bb) Cargo Deck strength (helicopter deck): 2,5 mt/sq.m
cc) Icebreaking capability: 1,5 m no jam ice in the continuous mode.

3 Machinery

a) BHP of Main Engines: 6x4140 Hp
b) Engine Builder: WARTSILA ZULTZER
c) Number of Engines & type: 6 Pcs Type 9ZL 40/48
d) Generators: HSSUL and YSPTL
e) Generator Builder: STROMBERG
f) Number of Generators & type: 6 pcs HSSUL 18/1057 D1; 5 pcs YSPTL 11/554 B16
g) Generator Capacity: HSSUL – 3800 Kwt; YSPTL – 1025 Kwt
h) Bow Thruster – Manufacturer: nil
i) Bow thruster rating (tons): nil
j) Stern Thruster – Manufacturer: nil
k) Stern thruster rating (tons): nil
l) Propellers / Rudders type: 3 fixed pitch screws, 4,3 m in diameter with 4 steel vanes of hardened steel. Max. speed of rotation 185 o\min.
m) Propellers / Rudders Manufacturer: Russia – Finland
n) Number & Pressure rating of air compressors: 2 pcs WP 370-30 kg/cm^2; 1 pc EK-16-2 8 kg/cm^2; 1pc WP – 25L100 – 35 kg/cm^2
o) Fuel Oil Metering system – Type & Manufacturer: KONTRAM
p) Pusher bow capable: nil
q) Water Makers Type of system installed: D 5U x 2 pcs; Osmos – RORO 3560 1 pcs
r) Water Maker Manufacturer: Russia; Germany
s) Total Daily Water Making Capacity: 40 m³
t) Daily water consumption: 10-20 m³

4 Towing & Anchor Handling Equipment

a) Stern Roller Dimension: Diam. 500 mm
b) Stern Roller SWL: 120 tn.
c) Towing Winch Manufacturer: RAUMA-REPOLA HV 60E-1 J
d) Winch Locations: stern towing winch accommodation
e) Drum Capacity: 500 m.
f) Brake Holding Capacity: 130 tn.
g) Bollard Pull: 120 tn
h) Towing Wires Construction: standard seal-Warrington
i) Towing Wire Diameters: 60 mm
j) Wire End Termination Details: LOOP
k) Spare Towing Wire Details: 240 m 60 mm
l) Tugger Winch Manufacturer: Nil
m) Winch Locations: - stern
n) Drum Capacity: - pls clarify
o) SWL: - pls clarify
p) Work Wires Construction: - pls clarify
q) Work Wires Diameter: - pls clarify
r) Work Wires & Termination Details: - pls clarify
s) Spare Working wire details: - pls clarify
t) Other Anchor Handling Equipment Details: Anchor "Holla" 3 pcs (1 spare)
u) Sharks Jaws SWL: pls clarify
v) Sharks Jaws Maximum Operational diameter: 63 mm pls clarify
w) Sharks Jaws Minimum Operational diameter: 63 mm pls clarify
x) Sharks Jaws Remote Operating Location: Forecast pls clarify
y) Towing Pins SWL: pls clarify
z) Towing Pins Maximum Operational diameter: pls clarify
aa) Towing Pins Minimum Operational diameter: pls clarify
bb) Remote Operating Location: Stern towing room

5 Deck Crane for Cargo Hose Handling - NIL

a) Crane SWL: bow port 2,4 tn: bow strbd 3,0 tn: helicopter deck port 10 tn
b) Crane reach & SWL Limitation details: bow 2,8-12,5 m: helicopter deck 3,2-16 m
c) Crane Location: 2 bow port/strbd: 1 helicopter deck port

6 Communication & Navigational Equipment

a) Single Joystick control & automatic heading control installed: No
b) GMDSS system installed: Yes
c) GMDSS System details and supporting equipment information: Skanti Combibridge 9250
TRP-9000 HF SSB: DSC-9000 MF/HF DSC: DSC 3000 VHF DSC
d) VHF marine band radio installed: Yes
e) VHF Locations: bridre port/strbd
f) Radar installation details: bridge port/strbd
g) Radar operating band: X-band S-band
h) Radar Maximum Range: 96 nm
i) Identification Radar transponder Installed: No
j) Radar operating bands: VHF – see point g)
k) Echo Sounder Installed: Yes
l) Gyrocompass installed: Yes
m) Gyro Type: KURS-4 x 2 pcs: VEGA 1 pcs
n) Number of independent systems: (Gyros ?) 3
o) Can Vessel send & receive email massages: Yes
p) Can vessel send & receive fax massage: Yes
q) Has the vessel got an auto pilot installation: Yes
r) Details of Electronic Navigational Equipment Installed: GPS FURUNO GP 80: MAGNAVOX MX 200: SHIPMATE RS 5300

7 Fire Fighting Equipment

a) Class (FiFi 1, FiFi 2 or FiFi 3):
b) Number of Fixed Fire Monitors: 2 pcs
c) Location of Fixed fire monitors: Bridge, watch room
d) Number of portable fire monitors: NIL
e) Foam tank Capacity: 7,5 cub.m
f) Engine room fire fighting system details: CO2 - 2790 kg

8 Accommodation Details

a) Crew + staff Berths: 72
b) Normal Total Complement: ?
c) Passenger Berths: 120
d) Total persons on board: 192

9 Galley

a) Freezer Space: 124 cub. m
b) Cooler Room Space: 353 cub. m

10 Pollution Response Materials and Equipment

a) Oil Dispersant Type: none
b) Oil Spill Dispersant tank capacity: none
c) Spray Equipment: none
d) Spray Booms: none
e) Skimmer Units: none
f) Pumps: none
g) Manifolds: none
h) Nozzles: none

11 Miscellaneous

a) Rescue & Stand by capability for 24-hour continuous operations: Yes
b) Oil spill drip tray and oil containment system installed to prevent pollution during hose breaking operations: No
c) Location and details of oil spill containment system for hose breaking operations: no
d) Addition storage space available 500M of floating oil spill recovery boom and skimmer units: No
e) Crew trained and capable of deployment of the oil spill recovery boom in 10 minutes: No
f) Vessel capable of supporting Diving and ROV maintenance work from the support vessel: No
g) Brief details of diving support and ROV capability: NIL
h) Vessel bunker consumption figures at sea provided of the absence of coming current and good weather conditions, i.e. winds maximum Beaufort force 3 (max 12 knots) and not exceeding Douglass Sea state 2.

ALL ABOVE DETAILS GIVEN FOR GOOD ORDER AND IN ACCORDANCE WITH BUILDING PLANS BUT ABOUT AND WOG.

12 Vessel Management and Operation

Vessel shall be managed and operated during the Charter Term By:

JSC MURMANSK SHIPPING COMPANY (DU), acting as manager of state owned icebreakers, registered at 15 Kominterna Street, Murmansk, 183038, Russia.

Table 2.1.1

Summary of Average NO_x Results

Wartsila 9ZL Main Propulsion Engine #5, KD-5/B1

May 20-21, 2007

Shell Offshore, Inc.
Frontier Discoverer Drilling Unit (Discoverer)
Norway

Method	Pollutant	Emission Unit	Run #			Average
80% LOAD CONDITION			**7**	**8**	**9**	
Power Produced	---	kW/hr	2,436	2,436	2,436	**2,436**
Method 7E	NO_x	ppm	701.0	639.0	723.2	**687.7**
	NO_x	lb/hr	93.4	94.4	106.4	**98.1**
	NO_x	lb/MMBtu	2.593	2.290	2.552	**2.478**
	NO_x	lb/KW-hr	0.0384	0.0387	0.0437	**0.0403**
57% LOAD CONDITION			**4**	**5**	**6**	
Power Produced	---	kW/hr	1,736	1,736	1,736	**1,736**
Method 7E	NO_x	ppm	478.7	492.9	501.4	**491.0**
	NO_x	lb/hr	51.7	48.3	47.5	**49.2**
	NO_x	lb/MMBtu	1.926	2.055	2.129	**2.037**
	NO_x	lb/KW-hr	0.0298	0.0278	0.0274	**0.0283**
35% LOAD CONDITION			**1**	**2**	**3**	
Power Produced	---	kW/hr	1,066	1,066	1,066	**1,066**
Method 7E	NO_x	ppm	359.7	413.5	385.5	**386.2**
	NO_x	lb/hr	32.5	36.0	32.7	**33.8**
	NO_x	lb/MMBtu	1.683	1.824	1.768	**1.758**
	NO_x	lb/KW-hr	0.0305	0.0338	0.0307	**0.0317**

TRC Environmental Corp.

EMISSION MEASUREMENTS DEPARTMENT

19874 141st Place N.E.
Woodinville, WA 98072
Phone: (425) 489-1938
Fax: (425) 489-9564

CLIENT:	Shell Offshore, Inc. - Norway	DATES:	5/20-21/2007
LOCATION:	Kapitan Dranitsyn	PROJECT NO.:	150614
UNIT:	Main Engine #5	PERSONNEL:	MM/PJC/MLE
CONDITION:	35% Load		

Data Input Sheet

The table below contains the results of testing and calculations performed by TRC on the date(s) listed.

Moisture & Airflow

Parameter	SYMBOL	UNITS	DATA			
Test Number			Run 1	Run 2	Run 3	
Test Date			5/20/2007	5/21/2007	5/21/2007	
Method 4 Start Time			2300	0021	0133	
Method 4 Stop Time			2400	0121	0233	3-RUN AVG.
Stack Diameter	ds	inches	30.0	30.0	30.0	
Barometric Pressure at Sampling Location	Pbar	in. Hg	29.95	29.95	29.95	29.95
Stack Static Pressure	Pg	in. H_2O	-0.7	-0.7	-0.7	-0.6550
Pitot Coefficient	cp	none	0.84	0.84	0.84	
Meter Calibration Factor	Y	none	0.976	0.976	0.976	
	DH@	none	1.678	1.678	1.678	
Stack Gas Oxygen Content	O_2	%	16.0	15.7	15.9	15.9
Stack Gas Carbon Dioxide Content	CO_2	%	3.9	3.9	3.9	3.9
Net Moisture Gain (Impingers w/SiGel)	Ww	grams	41.0	34.1	36.1	37.1
Average Stack Temperature	ts	deg F	478.6	477.5	474.1	476.7
Average Meter Temperature	tm	deg F	60.4	66.1	66.1	64.2
Avg Delta H	dH	in. H_2O	1.00	1.00	1.00	1.00
Average Square Root Delta H	ASR dH	in. H_2O	1.000	1.000	1.000	1.000
Avg Velocity Head	dP	in. H_2O	1.19	1.08	1.00	1.09
Average Square Root Delta P	ASR dP	in. H_2O	1.069	1.023	0.997	1.030
Gas Sample Volume	Vm	cu. ft.	35.890	35.980	35.580	35.817
Total Sampling Time	min	minutes	60	60	60	

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CLIENT:	Shell Offshore, Inc. - Norway	DATES:	5/20-21/2007
LOCATION:	Kapitan Dranitsyn	PROJECT NO.:	150614
UNIT:	Main Engine #5	PERSONNEL:	MM/PJC/MLE
CONDITION:	35% Load		

Calculation Sheet

The table below contains the results of testing and calculations performed by TRC on the date(s) listed.

Moisture & Airflow

Parameter	SYMBOL	UNITS	DATA			
Test Number			Run 1	Run 2	Run 3	
Test Date			5/20/2007	5/21/2007	5/21/2007	
Method 4 Start Time:			2300	0021	0133	
Method 4 Stop Time:			2400	0121	0233	
Calculated Data						**3-RUN AVG.**
Stack Area,As=3.14159*((Ds/12)/2)^2	As	sq.ft.	4.91	4.91	4.91	4.91
Avg Stack Temperature, Ts=ts+460	Ts	deg R	938.6	937.5	934.1	936.7
Meter Pressure, Pm=Pb+Dh/13.6	Pm	in. Hg	30.02	30.02	30.02	30.02
Avg Meter Temperature, Tm=tm+460	Tm	deg R	520.4	526.1	526.1	524.2
Gas Sample Volume at Standard Conditions, Vm(std)= 528/29.92*Y*Vm*Pm/Tm	Vm(std)	cu. ft.	35.666	35.362	34.969	35.333
		cu. m.	1.010	1.001	0.990	1.000
Net Moisture Gain (Impingers w/SiGel)	Ww	grams	41.0	34.1	36.1	37.1
Volume of Water Vapor, Vw(std)= 0.04715*Wlc	Vw(std)	cu. ft.	1.933	1.608	1.702	1.748
Moisture Fraction, Bws = Vw(Std)/(Vm(Std)+Vw(Std))*100	Bws	%	5.14%	4.35%	4.64%	4.71%
Dry Stack Gas Molecular Weight, Md = (0.32*O2)+(0.44*CO2)+(0.28*(100-(O2+CO2)))	Mwd	g/g-mole	29.26	29.25	29.26	29.26
Wet Stack Gas Molecular Weight Mw = Md* (1-Bws)+(18*(Bws))	Mws	g/g-mole	28.68	28.76	28.74	28.73
Absolute Stack Pressure, Ps = Pbar + Pg/13.6	Ps	in. Hg.	29.90	29.90	29.90	29.90
Stack Gas Velocity Vs= 85.49*Cp*ASRdP*((Ts)/((Ps)*(Mw)))^0.5	Vs	ft/sec	80.27	76.73	74.68	77.23
Vsm = 0.3048* Vs	Vsm	m/sec	24.47	23.39	22.76	23.54
Actual Stack Gas Flow Rate, Qa = 60*Vs*As	Qa	acf/min	23,641.2	22,599.0	21,995.0	22,745.1
Stack Gas Flow Rate (STP), Qsw = 528/29.92 * Qa * (Ps/Ts)	Qsw	scf/min	13,290.4	12,720.6	12,425.0	12,812.0
Dry Stack Gas Flow Rate (Dry, STP), Qsd = 528/29.92 * Qa * (1-Bws)* (Ps/Ts)	Qsd	dscf/min	12,607.0	12,167.4	11,848.3	12,207.6
		dscm/min	356.9	344.5	335.4	345.6

Sampling Data Summary

Parameter	SYMBOL	UNITS	Run 1	Run 2	Run 3	3-RUN AVG.
Total Sampling Time	min	minutes	60	60	60	60
Stack Gas Oxygen Content	O_2	%	16.0	15.7	15.9	15.9
Stack Gas Carbon Dioxide Content	CO_2	%	3.9	3.9	3.9	3.9
Gas Sample Volume at Standard Conditions,	Vm(std)	cu. ft.	35.666	35.362	34.969	35.333
		cu. m.	1.010	1.001	0.990	1.000
Dry Stack Gas Flow Rate (Dry, STP),	Qsd	dscf/min	12,607.0	12,167.4	11,848.3	12,207.6
		dscm/min	356.9	344.5	335.4	345.6

TRC Environmental Corp. EMISSION MEASUREMENTS DEPARTMENT

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CLIENT:	Shell Offshore, Inc. - Norway	DATES:	5/21/2007
LOCATION:	Kapitan Dranitsyn	PROJECT NO.:	150614
UNIT:	Main Engine #5	PERSONNEL:	MM/PJC/MLE
CONDITION:	57% Load		

Data Input Sheet

The table below contains the results of testing and calculations performed by TRC on the date(s) listed.

Moisture & Airflow

Parameter	SYMBOL	UNITS	DATA			
Test Number			Run 4	Run 5	Run 6	
Test Date			5/21/2007	5/21/2007	5/21/2007	
Method 4 Start Time			0246	0400	0512	
Method 4 Stop Time			0346	0500	0612	**3-RUN AVG.**
Stack Diameter	ds	inches	30.0	30.0	30.0	
Barometric Pressure at Sampling Location	Pbar	in. Hg	29.95	29.95	29.95	29.95
Stack Static Pressure	Pg	in. H_2O	-0.9	-0.9	-0.9	-0.8517
Pitot Coefficient	cp	none	0.84	0.84	0.84	
Meter Calibration Factor	Y	none	0.976	0.976	0.976	
	DH@	none	1.678	1.678	1.678	
Stack Gas Oxygen Content	O_2	%	15.2	15.4	15.5	15.4
Stack Gas Carbon Dioxide Content	CO_2	%	4.4	4.4	4.3	4.4
Net Moisture Gain (Impingers w/SiGel)	Ww	grams	36.1	38.1	34.1	36.1
Average Stack Temperature	ts	deg F	547.2	545.0	544.9	545.7
Average Meter Temperature	tm	deg F	64.1	67.9	67.1	66.4
Avg Delta H	dH	in. H_2O	1.00	1.00	1.00	1.00
Average Square Root Delta H	ASR dH	in. H_2O	1.000	1.000	1.000	1.000
Avg Velocity Head	dP	in. H_2O	1.76	1.45	1.34	1.52
Average Square Root Delta P	ASR dP	in. H_2O	1.319	1.199	1.152	1.224
Gas Sample Volume	Vm	cu. ft.	35.425	35.728	36.402	35.852
Total Sampling Time	min	minutes	60	60	60	

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CLIENT:	Shell Offshore, Inc. - Norway	DATES:	5/21/2007
LOCATION:	Kapitan Dranitsyn	PROJECT NO.:	150614
UNIT:	Main Engine #5	PERSONNEL:	MM/PJC/MLE
CONDITION:	57% Load		

Calculation Sheet

The table below contains the results of testing and calculations performed by TRC on the date(s) listed.

Moisture & Airflow

Parameter	SYMBOL	UNITS	DATA			
Test Number			Run 4	Run 5	Run 6	
Test Date			5/21/2007	5/21/2007	5/21/2007	
Method 4 Start Time:			0246	0400	0512	
Method 4 Stop Time:			0346	0500	0612	
Calculated Data						**3-RUN AVG.**
Stack Area,As=3.14159*((Ds/12)/2)^2	As	sq.ft.	4.91	4.91	4.91	4.91
Avg Stack Temperature, Ts=ts+460	Ts	deg R	1007.2	1005.0	1004.9	1005.7
Meter Pressure, Pm=Pb+Dh/13.6	Pm	in. Hg	30.02	30.02	30.02	30.02
Avg Meter Temperature, Tm=tm+460	Tm	deg R	524.1	527.9	527.1	526.4
Gas Sample Volume at Standard Conditions,	Vm(std)	cu. ft.	34.950	35.001	35.709	35.220
Vm(std)= 528/29.92*Y*Vm*Pm/Tm		cu. m.	0.989	0.991	1.011	0.997
Net Moisture Gain (Impingers w/SiGel)	Ww	grams	36.1	38.1	34.1	36.1
Volume of Water Vapor, Vw(std)= 0.04715*Wlc	Vw(std)	cu. ft.	1.702	1.796	1.608	1.702
Moisture Fraction, Bws = Vw(Std)/(Vm(Std)+Vw(Std))*100	Bws	%	4.64%	4.88%	4.31%	4.61%
Dry Stack Gas Molecular Weight, Md = (0.32*O2)+(0.44*CO2)+(0.28*(100-(O2+CO2)))	Mwd	g/g-mole	29.31	29.32	29.31	29.31
Wet Stack Gas Molecular Weight Mw = Md* (1-Bws)+(18*(Bws))	Mws	g/g-mole	28.79	28.77	28.82	28.79
Absolute Stack Pressure, Ps = Pbar + Pg/13.6	Ps	in. Hg.	29.89	29.89	29.89	29.89
Stack Gas Velocity Vs= 85.49*Cp*ASRdP*((Ts)/((Ps)*(Mw)))^0.5	Vs	ft/sec	102.50	93.13	89.38	95.00
Vsm = 0.3048* Vs	Vsm	m/sec	31.24	28.39	27.24	28.96
Actual Stack Gas Flow Rate, Qa = 60*Vs*As	Qa	acf/min	30,188.5	27,428.9	26,324.7	27,980.7
Stack Gas Flow Rate (STP), Qsw = 528/29.92 * Qa * (Ps/Ts)	Qsw	scf/min	15,808.6	14,394.3	13,816.4	14,673.1
Dry Stack Gas Flow Rate (Dry, STP),	Qsd	dscf/min	15,074.4	13,691.6	13,221.1	13,995.7
Qsd = 528/29.92 * Qa * (1-Bws)* (Ps/Ts)		dscm/min	426.8	387.6	374.3	396.2

Sampling Data Summary

Parameter	SYMBOL	UNITS	Run 4	Run 5	Run 6	3-RUN AVG.
Total Sampling Time	min	minutes	60	60	60	60
Stack Gas Oxygen Content	O_2	%	15.2	15.4	15.5	15.4
Stack Gas Carbon Dioxide Content	CO_2	%	4.4	4.4	4.3	4.4
Gas Sample Volume at Standard Conditions,	Vm(std)	cu. ft.	34.950	35.001	35.709	35.220
		cu. m.	0.989	0.991	1.011	0.997
Dry Stack Gas Flow Rate (Dry, STP),	Qsd	dscf/min	15,074.4	13,691.6	13,221.1	13,995.7
		dscm/min	426.8	387.6	374.3	396.2

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CLIENT:	Shell Offshore, Inc. - Norway	DATES:	5/21/2007
LOCATION:	Kapitan Dranitsyn	PROJECT NO.:	150614
UNIT:	Main Engine #5	PERSONNEL:	MM/PJC/MLE
CONDITION:	80% Load		

Data Input Sheet

The table below contains the results of testing and calculations performed by TRC on the date(s) listed.

Moisture & Airflow

Parameter	SYMBOL	UNITS	DATA			
Test Number			Run 7	Run 8	Run 9	
Test Date			5/21/2007	5/21/2007	5/21/2007	
Method 4 Start Time			0632	0745	0903	
Method 4 Stop Time			0732	0845	1003	**3-RUN AVG.**
Stack Diameter	ds	inches	30.0	30.0	30.0	
Barometric Pressure at Sampling Location	Pbar	in. Hg	29.95	29.95	29.95	29.95
Stack Static Pressure	Pg	in. H_2O	-3.0	-0.9	-3.0	-2.2833
Pitot Coefficient	cp	none	0.84	0.84	0.84	
Meter Calibration Factor	Y	none	0.976	0.976	0.976	
	DH@	none	1.678	1.678	1.678	
Stack Gas Oxygen Content	O_2	%	14.7	14.5	14.4	14.5
Stack Gas Carbon Dioxide Content	CO_2	%	4.9	4.9	5.0	4.9
Net Moisture Gain (Impingers w/SiGel)	Ww	grams	31.5	29.6	29.6	30.2
Average Stack Temperature	ts	deg F	607.2	608.7	611.3	609.0
Average Meter Temperature	tm	deg F	60.8	62.6	64.8	62.7
Avg Delta H	dH	in. H_2O	1.00	1.00	1.00	1.00
Average Square Root Delta H	ASR dH	in. H_2O	1.000	1.000	1.000	1.000
Avg Velocity Head	dP	in. H_2O	3.02	3.49	3.49	3.33
Average Square Root Delta P	ASR dP	in. H_2O	1.682	1.847	1.847	1.792
Gas Sample Volume	Vm	cu. ft.	30.743	35.785	35.609	34.046
Total Sampling Time	min	minutes	60	60	60	

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CLIENT:	Shell Offshore, Inc. - Norway	DATES:	5/21/2007
LOCATION:	Kapitan Dranitsyn	PROJECT NO.:	150614
UNIT:	Main Engine #5	PERSONNEL:	MM/PJC/MLE
CONDITION:	80% Load		

Calculation Sheet

The table below contains the results of testing and calculations performed by TRC on the date(s) listed.

Moisture & Airflow

Parameter	SYMBOL	UNITS	DATA			
Test Number			Run 7	Run 8	Run 9	
Test Date			5/21/2007	5/21/2007	5/21/2007	
Method 4 Start Time:			0632	0745	0903	
Method 4 Stop Time:			0732	0845	1003	
Calculated Data						**3-RUN AVG.**
Stack Area,As=3.14159*((Ds/12)/2)^2	As	sq.ft.	4.91	4.91	4.91	4.91
Avg Stack Temperature, Ts=ts+460	Ts	deg R	1067.2	1068.7	1071.3	1069.0
Meter Pressure, Pm=Pb+Dh/13.6	Pm	in. Hg	30.02	30.02	30.02	30.02
Avg Meter Temperature, Tm=tm+460	Tm	deg R	520.8	522.6	524.8	522.7
Gas Sample Volume at Standard Conditions, Vm(std)= 528/29.92*Y*Vm*Pm/Tm	Vm(std)	cu. ft.	30.526	35.411	35.088	33.675
		cu. m.	0.864	1.002	0.993	0.953
Net Moisture Gain (Impingers w/SiGel)	Ww	grams	31.5	29.6	29.6	30.2
Volume of Water Vapor, Vw(std)= 0.04715*Wlc	Vw(std)	cu. ft.	1.485	1.396	1.396	1.426
Moisture Fraction, Bws = Vw(Std)/(Vm(Std)+Vw(Std))*100	Bws	%	4.64%	3.79%	3.83%	4.09%
Dry Stack Gas Molecular Weight, Md = (0.32*O2)+(0.44*CO2)+(0.28*(100-(O2+CO2)))	Mwd	g/g-mole	29.37	29.36	29.38	29.37
Wet Stack Gas Molecular Weight Mw = Md* (1-Bws)+(18*(Bws))	Mws	g/g-mole	28.84	28.93	28.94	28.91
Absolute Stack Pressure, Ps = Pbar + Pg/13.6	Ps	in. Hg.	29.73	29.89	29.73	29.78
Stack Gas Velocity Vs= 85.49*Cp*ASRdP*((Ts)/((Ps)*(Mw)))^0.5	Vs	ft/sec	134.73	147.41	148.00	143.38
Vsm = 0.3048* Vs	Vsm	m/sec	41.07	44.93	45.11	43.70
Actual Stack Gas Flow Rate, Qa = 60*Vs*As	Qa	acf/min	39,681.6	43,415.5	43,590.0	42,229.1
Stack Gas Flow Rate (STP), Qsw = 528/29.92 * Qa * (Ps/Ts)	Qsw	scf/min	19,508.3	21,427.4	21,346.6	20,760.8
Dry Stack Gas Flow Rate (Dry, STP), Qsd = 528/29.92 * Qa * (1-Bws)* (Ps/Ts)	Qsd	dscf/min	18,603.2	20,614.9	20,530.1	19,916.0
		dscm/min	526.7	583.6	581.2	563.8

Sampling Data Summary

Parameter	SYMBOL	UNITS	Run 7	Run 8	Run 9	3-RUN AVG.
Total Sampling Time	min	minutes	60	60	60	60
Stack Gas Oxygen Content	O_2	%	14.7	14.5	14.4	14.5
Stack Gas Carbon Dioxide Content	CO_2	%	4.9	4.9	5.0	4.9
Gas Sample Volume at Standard Conditions,	Vm(std)	cu. ft.	30.526	35.411	35.088	33.675
		cu. m.	0.864	1.002	0.993	0.953
Dry Stack Gas Flow Rate (Dry, STP),	Qsd	dscf/min	18,603.2	20,614.9	20,530.1	19,916.0
		dscm/min	526.7	583.6	581.2	563.8

Odin Viking II

Function: Primary Icebreaker

Ship Dimensions
Length: 73.9 m
Width: 16.9 m
Propulsion: (4) MaK 6M32C (2,880 kW each)
Reference: Vessel Specifications

Stack Parameters (propulsion engines)
Height: 28.96 m
Diameter: 0.60 m
Velocity: 24.9 m/sec @ 80% load
Temperature: 579 K @ 80% load
Reference: Project Guide for MaK M32C engines

LATEST NEWS

15.12.2008 15:41:58
The partners in Trans Viking agree to divide ownership

19.11.2008 21:32:53
Sponsoring the local rescue service

08.09.2008 13:45:56
Viking scores high on FPAL

04.07.2008 10:07:49
Vessels being fitted with new secondary winches

News Archive

AHTS Odin Viking II - Main Characteristics

Design :
MOSSMAR 424 AHTS

Classification :
ABS,A1(E), OFFSHORE VESSEL, + AMS, + ACCU, ORO, DP 2, FIFI 2

Built / Delivered :
Havyard Leirvik, Norway - 03/2003 - IMO 9270397

Flag / Registered :
NOR

Owners :
Partrederiet Odin Viking DA

Commercial Managers :
Viking Supply Ships A/S, Kristiansand, Norway

Dimensions
Length Over All (LOA) : 73.85 metres
Length between p.p. : 65.00 metres
Breadth, moulded : 16.90 metres
Depth, moulded : 8.00 metres
Draught (scantling) : 7.45 metres
Draught (design) : 6.84 metres
Freeboard (min) : 1.18 metres

Tonnage
Dead Weight : 2,869 tonnes @ 6.84 metres
Light Ship : 1,950 tonnes @ 6.00 metres
Gross : 2,725 tonnes
Net : 817 tonnes

Capacities
Dry Bulk : 220 m 3 in 4 tanks - totalling 8,000 ft 3
Pot Water : 796 m 3 (stab. tanks incl.)
Drill Water / Ballast : 1,022 m 3 (chain lockers incl.)
Brine : 587 m 3 – SG 2.5 (Dual purpose – in OBM tanks)
Oil Based Mud : 587 m 3 – SG 2.8 (Dual purpose – in Brine tanks)
Base Oil : 161 m 3 (Dual purpose – in Fuel Oil tanks)
Fuel Oil : 1,131 m 3 Marine Gas Oil (Diesel)
Oil Recovery (ORO) : 1,054 m 3
Diesel Overflow : 12.9 m 3 with alarm
Diesel Service / Settling : 2 x 27.9 m 3 / 1 x 42.2 m 3 / 1 x 40.6 m 3
Deck Load : Abt 1,000 ts
Deck Area : 546 m 2 / 39,30 m x 13,90 m

Discharge Rates / Lines etc.
Dry Bulk : 2 x 25 m 3/h compressors – 80 psi. Two separate discharge systems.
Discharge rate 2 x 75 m 3 / hr at 90 metres head
Pot Water : Discharge rate 1 x 200 m 3 / hr at 9 bar
Drill Water / Ballast : Discharge rate 1 x 200 m 3 / hr at 9 bar
Brine : Discharge rate 2 x 75 m 3 / hr at 9 bar
Oil Based Mud : Discharge rate 2 x 75 m 3 / hr at 9 bar - Oil Mud Agitators fitted
Base Oil : Discharge rate 1 x 75 m 3 / hr at 9 bar
Fuel Oil (Diesel) : Discharge rate 1 x 200 m 3 / hr at 9 bar
Oil Recovery : Discharge rate 1 x 75 m 3 / hr at 9 bar
Discharge Stations : All products mid and aft both SB and PS
Discharge Lines : 6 inch Weco system with reducers for Pot / Drill Water, Fuel Oil and Dry Bulk
: 5 inch Weco system with reducers for Brine, Base Oil and Oil Base Mud
Tank cleaning : Mud and Base Oil tanks fitted with permanent tank cleaning system
Flow Meters : Flow meters fitted for Pot Water and Fuel Oil (Digital display + printer for MGO)

Propulsion
Main Engine : MAK 4 X 2,880 kW at 600 RPM – Total output 11,520 kW
Thrusters : 2 Bow 883 kW in Tunnel (Electr) + 1 Azimuth 883 kW 360 deg retr = 2649 kW
: 1 Stern in tunnel 883 KW (Electrical)
Propellers : 2 KaMeWa 4 blades in nozzles – dia 3.9 metres - 152 RPM
Rudders : 2 High Lift Flap Rudders , 7.6 sm ,

Bollard Pull
Bollard Pull : 180 continuous (ABS certified) / Abt 185 max pull

Speed/Consumption
Speed/Consumption : 15.5 knots – Abt. 44 MT / 24 hrs at 6.0 meter draught
13.5 knots – Abt. 22 MT
10.0 knots – Abt. 10 MT

Towing & Anchorhandling Equipment
AHT Winch : Brattvaag tow/anchorhandling triple drum 400 ts pull / 550 ts brake holding cap
AHT Drum : Two of 1,200 mm x 3.200 dia x 1,600 mm length

CONTACT US

Viking Supply Ships AS
Kirkegaten 1
P.O Box 204
N - 4662 KRISTIANSAND
NORWAY

Ph: **+47 38 12 41 70**

Wire Capacity : 2 x 1,880 m of 77 mm wire or 2 x 1,650 m of 83 mm wire
AH Drum : One of 1,200 mm x 3,200 mm dia. x 4,600 mm length
Wire Capacity : 5,490 m of 77 mm wire
Winch Control : TOWCON 2000 Aut. Control with printer
Pennant Reels/Caps : One fixed drum with two dividing flanges with cut out
1 x 1,830 m of 77 mm wire, 2 x 1,435 m of 77 mm wire
Cable Lifters : 2 x 76 mm + 1 x 84 mm
Chain Lockers : Total 420 m3 - 2 x 113 m 3 + 2 x 97 m 3 giving abt 2 x 6,000 ft cap of 3 inch chain
Shark Jaws : 2 Karm Forks arranged for chain up to 165 mm dia / 650 ts SWL
Inserts for handling 65, 75, 85, 100, and 120 mm dia. wire/chain
Stern Roller : One of 3 m dia. x 6.0 m length – SWL 550 ts
Guide Pins : 2 pairs of Karm Fork Hydraulic pins – SWL 330 ts

Workwires
Work Wire : 200 metres of 77 mm dia
Chase Wire : 1,500 metres of 77 mm dia
Main Tow Wire : 1,500 metres of 77 mm dia

Deck Equipment
Capstans : 2 x 10 ts pull
Tugger Winches : 2 x 15 ts pull
Cranes : 1 telescopic crane on fore cargo deck giving 5 ts / 8,3 ts at 15 m / 9,3 m arm
1 crane on aft cargo deck giving 1.58 ts at 12 m arm (360 degr)
Windlass : 1 hydraulic windlass / mooring winch. Two de-clutchable drums 40 mm K3 chain

Accommodation
Accommodation for a total of 26 persons, including crew
All accommodation equipped with air-condition and humidification facilities.

Misc .
Fi-Fi (FIFI II) : 2 x pumps, Kvaerner Eureka. Capacity 3,600 m 3/hr @ 16 bar at 1,530 rpm
: 3 x water Monitors 2,400 m 3/hr
DynPos 2 : Kongsberg Simrad
Reference System : DGPS + Fan Beam

Particulars believed to be correct, without guarantee.

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15. Exhaust system

Position of exhaust gas nozzle:

A nozzle position of 0, 30 and 60 is possible.
The basic position is 30°. 0° or 60° are reached by using an elbow.

Exhaust compensator:

	Diameter DN	Length [mm]
6 M 32 C	600	450
8/9 M 32 C	700	520

Design of the pipe cross-section:

The pressure loss is to be minimized in order to optimize fuel consumption and thermal load of the engine.

Max. flow velocity: 40 m/s (guide value).

Max pressure loss (incl. silencer and exhaust gas boiler): 30 mbar
(lower values will reduce thermal load of the engine).

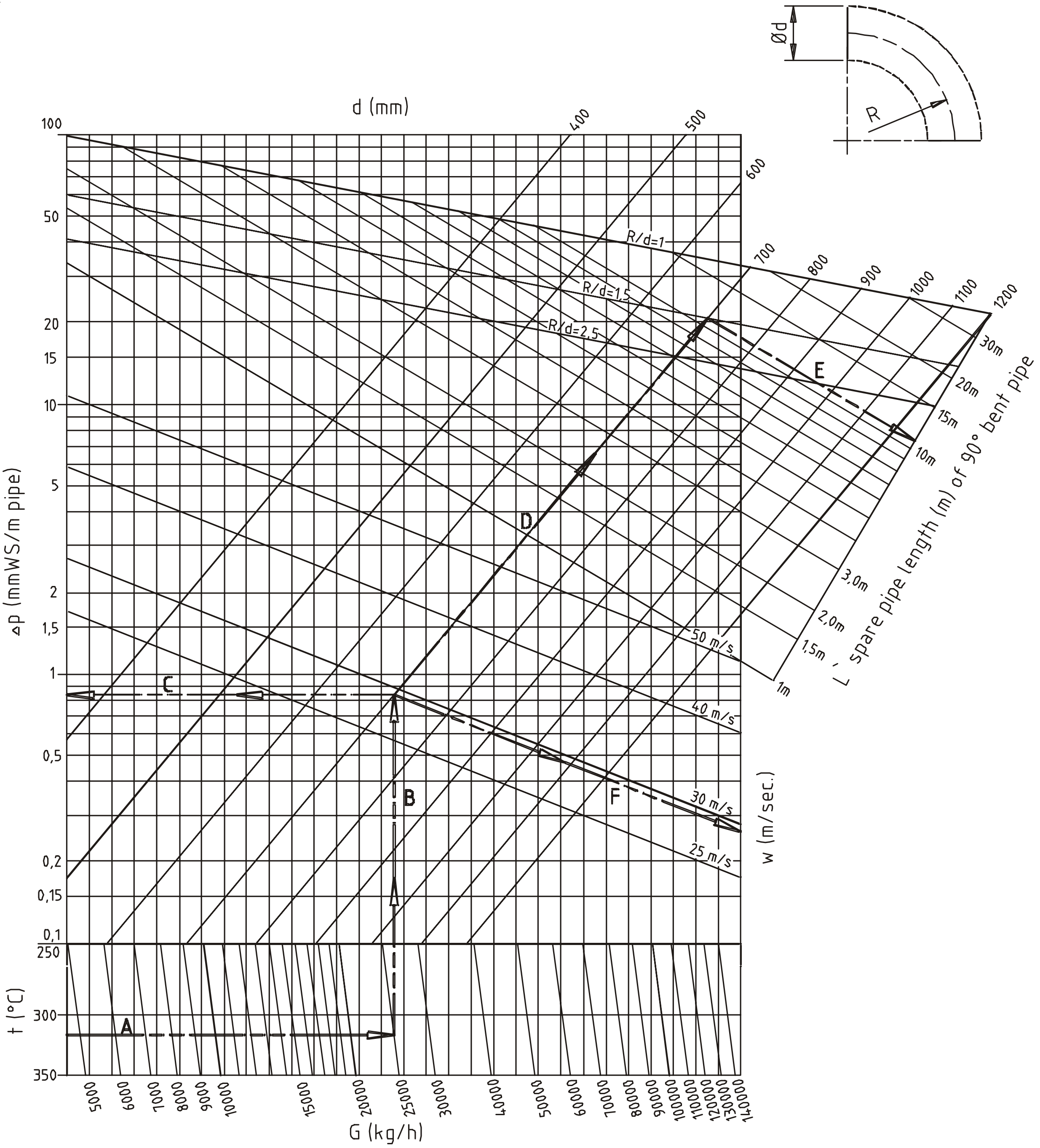
Notes regarding installation:

- Arrangement of the first expansion joint directly on the transition piece
- Arrangement of the first fixed point in the conduit directly after the expansion joint
- Drain opening to be provided (protection of turbocharger and engine against water)
- Each engine requires an exhaust gas pipe (one common pipe for several engines is **not permissible).**

If it should be impossible to use the standard transition piece supplied by Caterpillar Motoren, the weight of the transition piece manufactured by the shipyard must not exceed the weight of the standard transition piece. A drawing including the weight will then have to be submitted approval.

15. Exhaust system

Resistance in exhaust gas piping



Example (based on diagram data A to E):

t = 335 °C, G = 25000 kg/h

l = 15 m straight pipelength, d = 700 mm

3 off 90° bend R/d = 1.5

1 off 45° bend R/d = 1.5

ΔPg = ?

Δp = 0.83 mm WC/m

L' = 3 · 11 m + 5.5 m

L = l + L' = 15 m + 38.5 m = 53.5 m

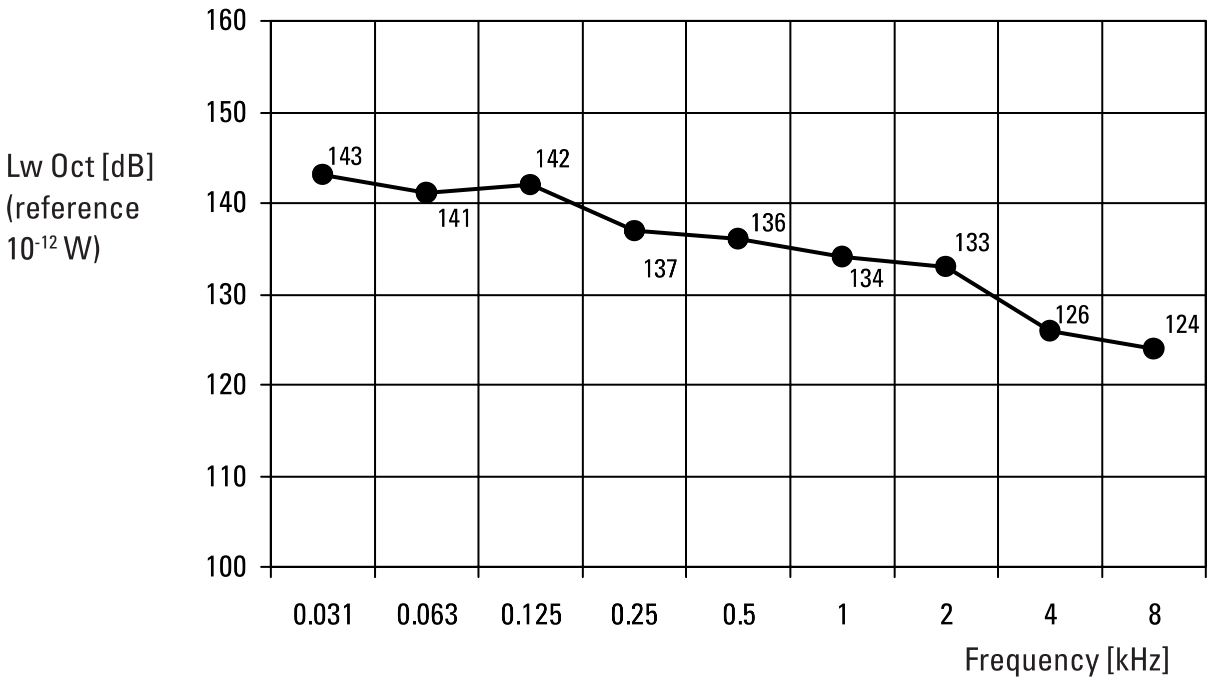
ΔPg = Δp · L = 0.83 mm WC/m · 53.5 m = 44.4 mm WC

t	= Exhaust gas temperature	(°C)
G	= Exhaust gas massflow	(kg/h)
Δp	= Resistance/m pipe length	(mm WC/m)
d	= Inner pipe diameter	(mm)
w	= Gas velocity	(m/s)
l	= Straight pipe length	(m)
L'	= Spare pipe length of 90° bent pipe	(m)
L	= Effective substitute pipe length	(m)
ΔPg	= Total resistance	(mm WC)

15. Exhaust system

Exhaust sound power level Lw, not attenuated [1 x 1 m from open pipe] (to be expected)

The noise measurements are made with a probe inside the exhaust pipe.



Tolerance $\pm$ 2 dB

15. Exhaust system

Exhaust data (preliminary):

Tolerance: 10 %
Atmospheric pressure: 1 bar
Relative humidity: 60 %
Constant speed

Intake air temperature: 25 °C

	Output [kW]	• Output % • [kg/h] • [°C]					
		100	90	80	70	60	50
6 M 32 C	3000	20400	17312	16400	14400	12400	10400
		321	327	333	342	354	367
8 M 32 C	4000	29300	27200	23220	20200	17000	13900
		332	338	344	357	377	397
9 M 32 C	4500	30800	28284	25361	22163	18863	15618
		330	338	342	355	375	385

Intake air temperature: 45 °C

	Output [kW]	• Output % • [kg/h] • [°C]					
		100	90	80	70	60	50
6 M 32 C	3000	19585	16620	15745	13825	11205	9985
		340	347	353	363	375	389
8 M 32 C	4000	28130	26110	22290	19390	16320	13345
		352	358	365	378	399	421
9 M 32 C	4500	29570	27150	24345	21275	18100	14995
		350	358	363	376	397	408

All values for single log charging. Pulse charging values: on request.

Talagy

Function: Primary / Secondary Icebreaker

Ship Dimensions
Length: 73.3 m
Width: 17.3 m
Propulsion: (2) Sulzer 12ZV40/48 (6,264 kW each)
Reference: Vessel Specifications

Stack Parameters (propulsion engines)
Height: 25.91 m
Diameter: 0.80 m
Velocity: 43.7 m/sec @ 80% load
Temperature: 594 K @ 80% load
Reference: Stack test for similar Sulzer engine on Kapitan Dranitsyn - 5/21/2007

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Company activity
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Fleet / AHTS "TALAGY"

General Description		Principal Dimensions	
Vessel's Name	Talagy	Length Overall	79,34 m
Owner's Name	THEOGLOBAL Ltd	Breadth	17,25 m

Attachment F, Page 53

Operator Name	FEMCO-Management Ltd	Depth	10,0 m
Built	1979, Canada	Draft (max)	8,35 m
Flag	Russian Federation	Gross Tonnage	3898 GRT
Port of Registry	Kholmsk, Russia	Net Tonnage	1169 NRT
Call sign	U E N L	Deadweight	2066 mt
Classification	Lloyds+100A1Icebreaker tug	**Propulsion & Performance**	
Type	Anchor Handling Tug Supply	Main Engine:	2 x 8400 Shulzer 12 ZV 40/48 , Total 16 800 BHP
Registered Number	7824261	Bow Thrusters:	1 x 1180 BHP 880 kW
IMO Number		Stern Thrusters:	1 x 1180 BHP 880 kW
Capacity		Propellers:	1 x Controllable Pitch Propeller in Fixed Nozzles
Fuel Oil	1302.7 cub.m	Generators:	4 x CAT 353 300 kW = 1200 kW 440 V 3 phase
Potable Water	32.6 cub.m	Shaft Generators:	2 x Siemens – 1570 KVA – 400V – 60 Hz
Drill/Ballast	1400.0 cub.m	Bollard Pull:	**196 metric tons**
Dry Bulk		Rudders:	
Liquid Mud		**Speed/Fuel Consumption**:	
Oily bridge tank	136.9 cub.m	Maximum Speed	
Deck Cargo	600 mt	Cruising Speed	13 kts - 25.0 tons/day
Clear Deck Space	450 sq.m	Economical Speed	10 kts - 24.0 tons/day
Deck Strength	5 tns/sq.m	Port Usage	2.0 tons/day
Mooring System		**Towing and Anchor Handling Equipment**	
Anchor	2 x Meon Stockless 2522 kg	Anchor Handling Winch – Bruselle M48 Fabr. Triple drum waterfall type	
Anchor Windlass	1 x Pacific Winch	Removal speed	
Anchor Chain	46 mm, 1103 m	AH/Tow drum wire cap.	
Cargo Handling Equipment		Spooling drum	
Deck crane (Derrics)	FAVCO MODEL SDR 750 - 20 tn / 8 tn for 3 m / 16 m	Main tow line / Spare tow line	900 meter, size D 76 mm – SWL 216.6 mt / 2 x 1000 m
Tugger Winch:	2 x Pacific winches Staffa B400 – 10 tn	Chain lockers	
Capstans		A/H Tong	
Navigation/Communication		Towing pins	
Log Ben	Yes	Stern roller	
Main radio	Yes	Rig chain gypsies	
Aeronautical VHF SSB 1	Yes	Joystick Ulstein	
Satellite navigator	Yes	**Discharge rates**	
Radio direction finder	Yes	Fuel Oil	71,6 cub.m/hr
Gyro Compass	Yes	Potable Water	63,0 cub.m/hr
Magnetic Compass	Yes	Drill/Ballast	63,0 cub.m/hr
Auto Pilot	Yes	Dry Bulk	
Radars	Yes	Liquid mud	
Navtex	Yes	**OIL RECOVERY**	
Echo sounder	Yes	Recovered oil	
VHF Radio	Yes	Transfer pumps	
GMDSS	Yes	**Safety Equipment**	
Inmarsat Mini M phone/fax	Yes	All safety equipment as per SOLAS requirements	4 x 25 + 2 x 20 MAN LIFERAFTS = 140 persons
Portable VHF	Yes	**Accommodation**	
Telex TT 1558		Total - 34 BUNK SPACES	
FIRE FIGHTING SAFETY		**STAND-BY RESCUE**	
Pumps		Rescue capacity	
Monitors		MOB boats	
Throw height/length		Rescue Nets/Baskets	
ANTI-POLLUTION SYSTEM		Non-survivors	
Dispersant storage		Treatment room	
Booster pumps			

Balder Viking

Function: Secondary Icebreaker

Ship Dimensions
Length: 83.7 m
Width: 18.0 m
Propulsion: (2) MaK 8M32C (3,840 kW each)
(2) MaK 6M32C (2,880 kW each)
Reference: Vessel Specifications

Stack Parameters (propulsion engines)
Height: 28.96 m
Diameter: 0.70 m
Velocity: 24.9 m/sec @ 80% load
Temperature: 579 K @ 80% load
References: Project Guide for MaK M32C engines
Stack test of same engine type on Tor Viking II - 5/18/2007

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04.07.2008 10:07:49
Vessels being fitted with new secondary winches

News Archive

AHTS/Icebreaker Balder Viking - Main Characteristics

Design:
KMAR 808 AHTS/ ICEBREAKER (Now; MOSSMAR)

Classification:
DnV,+1A1, SUPPLY VESSEL, SF, TUG ICEBREAKER ICE-10, DK(+) EO HELDK-SH DYNPOS-AUTR HL(2,8) W1-OC

Built / Delivered:
Havyard Leirvik, Norway - 10/2000 - IMO 9199634

Registered / Flag:
Skärhamn, Sweden

Owners:
Trans Viking Icebreaking & Offshore AS , Kristiansand, Norway

Commercial Managers:
Viking Supply Ships A/S, Kristiansand, Norway

Dimensions
Length Over All (LOA): 83.70 metres
Length between p.p.: 75.20 metres
Breadth, moulded: 18.00 metres
Depth, moulded: 8.50 metres
Draught (scantling): 7.20 metres
Draught (design): 6.00 metres
Freeboard (design): 2.50 metres

Tonnage
Dead Weight: 2,528 tonnes
Light Ship: 4,289 tonnes
Gross: 3,382 tonnes
Net: 1,145 tonnes

Capacities
Dry Bulk: 283 m 3 in 4 tanks - totalling 10,000 ft 3
Pot Water: 724 m 3
Drill Water / Ballast: 1,205 m 3
Brine: 400 m 3 – SG 2.5
Oil Based Mud: 657 m 3 – SG 2.8
Base Oil: 242 m 3
Fuel Oil: 1,190 m 3 Marine Gas Oil (Diesel)
Urea: 94 m 3
Diesel Overflow: 21 m 3 with alarm
Diesel Service / Settling: 2 x 20 m 3
Deck Load: Abt 1,350 ts
Deck Area: 603 m 2 / 40.20 m x 15.0 m

All products in dedicated tanks – no dual purpose tanks

Discharge Rates / Lines etc.
Dry Bulk: 2 x 25 m 3/h compressors – 80 psi. Two separate discharge systems.
Discharge rate 2 x 75 m 3 / h at 90 metres head
Pot Water: Discharge rate 1 x 250 m 3 / h at 9 bar
Drill Water / Ballast: Discharge rate 1 x 250 m 3 / h at 9 bar
Brine: Discharge rate 2 x 75 m 3 / h at 18 bar
Oil Based Mud: Discharge rate 2 x 75 m 3 / h at 24 bar - Oil Mud Agitators fitted
Base Oil: Discharge rate 1 x 75 m 3 / h at 9 bar
Fuel Oil (Diesel): Discharge rate 1 x 250 m 3 / h at 9 bar
Discharge Stations: All products mid and aft both SB and PS
Discharge Lines: 6 inch Weco system with reducers for Pot / Drill Water, Fuel Oil and Dry Bulk: 5 inch Weco system with reducers for Brine, Base Oil and Oil Base Mud
Tank cleaning: Mud and Base Oil tanks fitted with permanent tank cleaning system and heating
Flow Meters: Flow meters fitted for Pot Water and Fuel Oil (Digital display + printer for MGO)

Propulsion
Main Engine: MAK 18,300 BHP - 4 eng (father/son) 2 x 3,840 kW + 2 x 2,880 kW = 13,440 kW
Thrusters: Bow 1,200 BHP in tunnel (Electr) + 1,200 BHP 360 deg retractable = 2,400 BHP: Stern 1,200 BHP in tunnel (Electrical)
Propellers: 2 KaMeWa 4 blades in nozzles – dia abt 4.0 metres
Rudders: 2 spade rudders

Bollard Pull
Bollard Pull: 201 continuous (DnV certified) / Abt. 210 max pull

Speed/Consumption
Speed/Consumption: 16 knots – Abt. 42.7 MT / 24 hrs at 6.0 metres draught
: 12 knots – Abt. 15.6 MT
: 10 knots – Abt. 8.6 MT

Towing & Anchorhandling Equipment

CONTACT US

Viking Supply Ships AS
Kirkegaten 1
P.O Box 204
N - 4662 KRISTIANSAND
NORWAY

Ph: **+47 38 12 41 70**

AHT Winch: Brattvaag towing/anchorhandling winch 400 ts pull / 550 ts brake holding cap
AHT Drum: One of 1,400 mm dia. x 3,750 dia x (1,250 mm + 1,250 mm) length
Wire Capacity: 2 x 1,900 metres of 77 mm wire or 2 x 1,650 metres of 83 mm wire
AH Drum: One of 1,400 mm dia. x 3,750 mm dia. x 3,000 mm length
Wire Capacity: 4,100 metres of 83 mm wire
Winch Control: TOWCON 2000 Automatic Control with printer
Pennant Reels / Caps: 1 off 2 x 1,500 metres of 77 mm wire or 2 x 1,300 metres of 83 mm wire
: 1 off 6,700 metres of 77 mm wire or 5,580 metres of 83 mm wire – 72.0 ts pull
Alt Fibre Rope Capacity: 1,000 metres of 190 mm fibre rope.
Large Reel Inner Core: 1,500 mm dia
Cable Lifters: 2 x 76 mm and 2 x 84 mm onboard
Chain Lockers: 2 x 129 m 3 / giving abt 2 x 6,000 ft of 3 inch chain
Shark Jaws: 2 pairs of Karm Forks arranged for chain up to 165 mm dia / 750 ts SWL
Inserts for handling of 65, 75, 85, 100, and 120 mm dia. wire/chain
Stern Roller: One of 3,5 metres dia. x 6.0 metres length – SWL 500 ts
Guide Pins: 2 pairs Karm Fork Hydraulic pins – SWL 170 ts
Workwires
Work Wire: 300 metres of 77 mm dia.
Chaise Wire: 1,000 metres of 83 mm dia.
Main Tow Wire: 1,500 metres of 83 mm dia.
Spare Tow Wire: 1,300 metres of 83 mm dia.
Deck Equipment
Capstans: 2 x 15 ts pull
Tugger Winches: 2 x 15 ts pull
Smit Brackets: One bracket on B Deck Forward – SWL 250 ts
Cranes: 1 hydraulic crane on fore cargo deck giving 6 / 12 ts at 20/10 m arm (360 degr)
: 1 telescopic crane on aft cargo deck giving 1.5 / 3 ts at 15/10 m arm (360 degr)
: 1 hydraulic crane on for-castle deck for stores etc
Windlass: 1 hydraulic windlass / mooring winch. 2 declutch-able drums 46 mm K3 chain
Accommodation
Accommodation of a total of 23 persons, including crew.
All accommodation equipped with air-condition and humidification facilities.

Dynamic Positioning
The vessel is equipped with Kongsberg Simrad SDP 21 Redundant DP System - GreenDP

Misc.
We would like to highlight the exceptional good manoeuvrability of the vessel. Also please note the environmental bonus using "Balder Viking" due to her exceptional low noise level, and the installed Exhaust Gas Treatment Systems (Catalyst), effectively reducing the NOx levels. "Balder Viking" is also equipped with diesel overflow tank with alarm system. The vessels design, and her possibility for running 2 engines, ("father/son") gives favourable fuel consumption.

Furthermore, we will highlight the vessels DynPos system, the new Kongsberg Simrad design; GreenDP which is new concept for fuel tight DP. GreenDP is environment friendly and reduces fuel consumption significantly, and reduces wear and tear of thrusters and diesels due to very smooth control actions. GreenDP also increase the operational reliability of the vessel.

The vessel is also equipped with spooling gear.

Particulars believed to be correct, without guarantee.

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15. Exhaust system

Position of exhaust gas nozzle:

A nozzle position of 0, 30 and 60 is possible.
The basic position is 30°. 0° or 60° are reached by using an elbow.

Exhaust compensator:

	Diameter DN	Length [mm]
6 M 32 C	600	450
8/9 M 32 C	700	520

Design of the pipe cross-section:

The pressure loss is to be minimized in order to optimize fuel consumption and thermal load of the engine.

Max. flow velocity: 40 m/s (guide value).

Max pressure loss (incl. silencer and exhaust gas boiler): 30 mbar
(lower values will reduce thermal load of the engine).

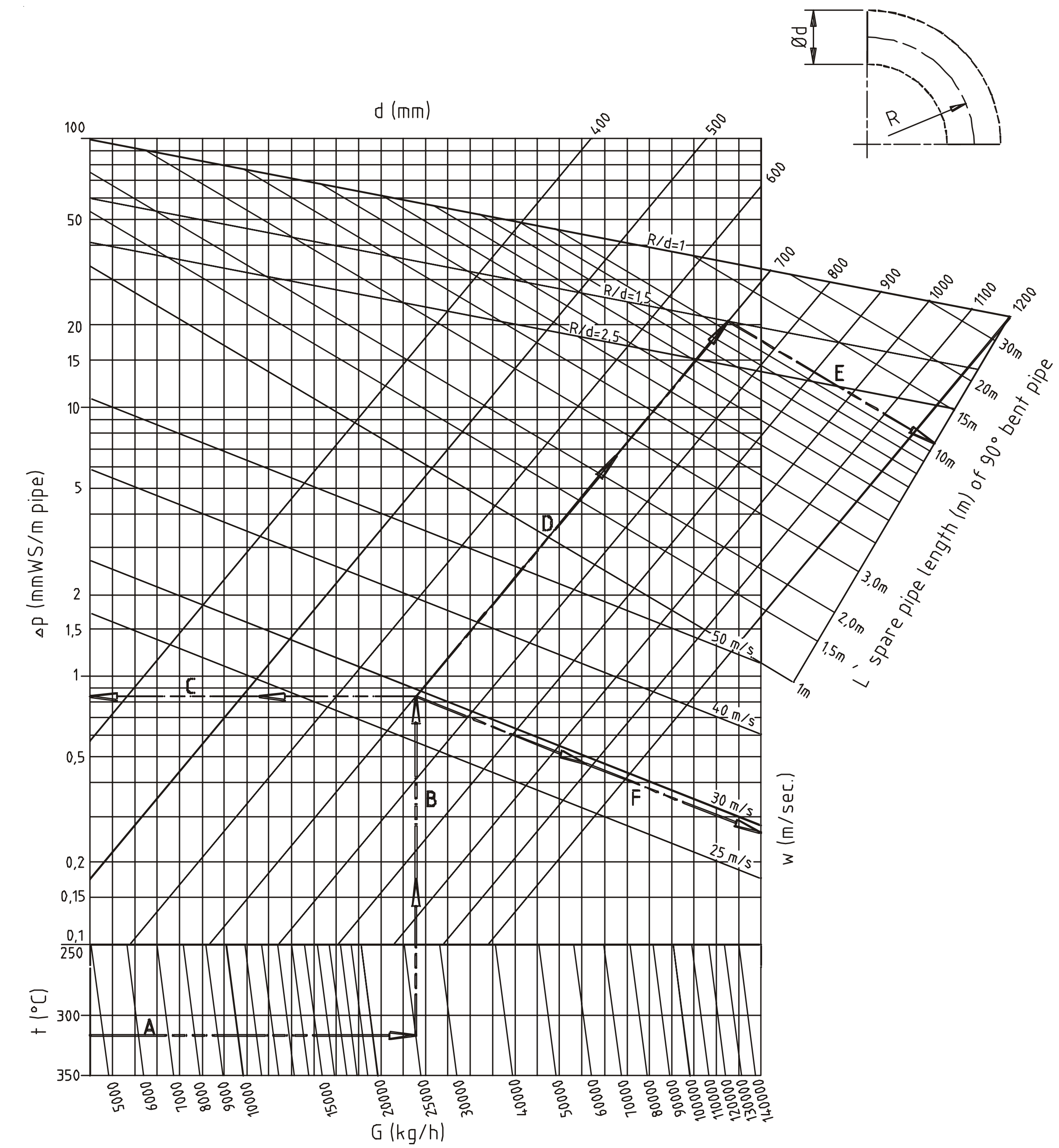
Notes regarding installation:

- Arrangement of the first expansion joint directly on the transition piece
- Arrangement of the first fixed point in the conduit directly after the expansion joint
- Drain opening to be provided (protection of turbocharger and engine against water)
- Each engine requires an exhaust gas pipe (one common pipe for several engines is **not permissible).**

If it should be impossible to use the standard transition piece supplied by Caterpillar Motoren, the weight of the transition piece manufactured by the shipyard must not exceed the weight of the standard transition piece. A drawing including the weight will then have to be submitted approval.

15. Exhaust system

Resistance in exhaust gas piping



Example (based on diagram data A to E):

t = 335 °C, G = 25000 kg/h
l = 15 m straight pipelength, d = 700 mm
3 off 90° bend R/d = 1.5
1 off 45° bend R/d = 1.5
ΔPg = ?

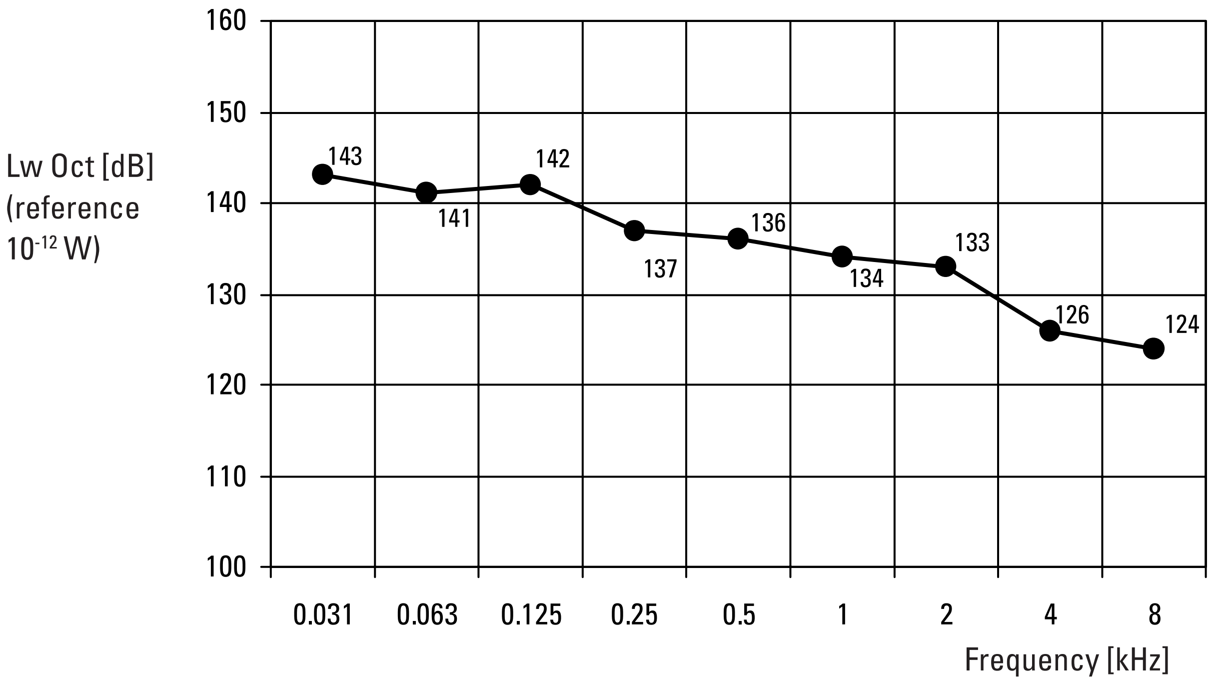
Δp = 0.83 mm WC/m
L' = 3 · 11 m + 5.5 m
L = l + L' = 15 m + 38.5 m = 53.5 m
ΔPg = Δp · L = 0.83 mm WC/m · 53.5 m = 44.4 mm WC

t	=	Exhaust gas temperature	(°C)
G	=	Exhaust gas massflow	(kg/h)
Δp	=	Resistance/m pipe length	(mm WC/m)
d	=	Inner pipe diameter	(mm)
w	=	Gas velocity	(m/s)
l	=	Straight pipe length	(m)
L'	=	Spare pipe length of 90° bent pipe	(m)
L	=	Effective substitute pipe length	(m)
ΔPg	=	Total resistance	(mm WC)

15. Exhaust system

Exhaust sound power level Lw, not attenuated [1 x 1 m from open pipe] (to be expected)

The noise measurements are made with a probe inside the exhaust pipe.



Tolerance $\pm$ 2 dB

15. Exhaust system

Exhaust data (preliminary):

Tolerance: 10 %
Atmospheric pressure: 1 bar
Relative humidity: 60 %
Constant speed

Intake air temperature: 25 °C

	Output [kW]	• Output % • [kg/h] • [°C]					
		100	90	80	70	60	50
6 M 32 C	3000	20400	17312	16400	14400	12400	10400
		321	327	333	342	354	367
8 M 32 C	4000	29300	27200	23220	20200	17000	13900
		332	338	344	357	377	397
9 M 32 C	4500	30800	28284	25361	22163	18863	15618
		330	338	342	355	375	385

Intake air temperature: 45 °C

	Output [kW]	• Output % • [kg/h] • [°C]					
		100	90	80	70	60	50
6 M 32 C	3000	19585	16620	15745	13825	11205	9985
		340	347	353	363	375	389
8 M 32 C	4000	28130	26110	22290	19390	16320	13345
		352	358	365	378	399	421
9 M 32 C	4500	29570	27150	24345	21275	18100	14995
		350	358	363	376	397	408

All values for single log charging. Pulse charging values: on request.

Fennica / Nordica

Function: Secondary Icebreaker

Ship Dimensions
Length: 116.0 m
Width: 26.0 m
Propulsion: (2) Wartsila 16V32 (6,000 kW each)
Reference: Vessel Specifications

Stack Parameters (propulsion engines)
Height: 32.0 m
Diameter: 0.80 m
Velocity: 38.4 m/sec @ 80% load
Temperature: 655 K @ 80% load
References: Stack test - 5/25/2007

Powerful, high-tech, multipurpose vessels for global underwater oil field construction

Designed for the management, maintenance and service of offshore oil wells, the 97-metre Botnica is a multipurpose vessel specialised in marine construction and icebreaking, as are the 116-metre vessels Fennica and Nordica. They are equipped with diesel-electric propulsion systems and their innovative combination of capabilities, based on extensive design and engineering work, facilitates their use in both arctic and tropical conditions. All three of these multipurpose vessels are highly advanced, powerful and extremely well designed and built.

Unique technology for demanding conditions

These vessels are ideal for offshore operations. The working deck is about 1,000 m^2, making it exceptionally large and level for ships of this length. The deck was designed for fast equipment changes. Depending on the ship, such equipment may range from simple deck cranes to a 160-tonne pedestal active heave compensated crane, or from deepwater installation equipment to pipe-laying systems, underwater machinery control or the towing and installation of large pipelines.

With their 15,000 kW power output and 230-tonne bollard pull, the Nordica and the Fennica are ideal for seabed ploughing and towing, and they are also fully equipped for anchor-handling operations. The ships' main engine and generator solution makes it possible to perform heavy-duty maintenance tasks without affecting their operating ability.

Both the Fennica and the Nordica are also equipped with a stern roller.

Accurate, safe and highly suitable

The Botnica's moon pool and the large size of its working deck make this ship highly suitable for a variety of offshore operations. Different types of special tools and structures can be installed on the working deck. The attributes of the Botnica, a class 3 DP ship, are in keeping with the strict rules and stipulations demanded in oil well management, as well as the requirements on oil fields set by the Norwegian Maritime Directorate.

The multipurpose icebreakers are equipped with Kongsberg Simrad's Dynamic Positioning (DP) system, which has five independent control units operating their main propellers and three bow thrusters. Even in a sector in which ocean vessels equipped with DP systems are a normal sight, these vessels have performed their tasks exceptionally well in terms of manoeuvrability and accuracy. Their unusual asymmetrical and spacious navigation bridge was designed with an eye to the requirements placed on the ship's multiple applications, both on the open sea and in icebreaking and towing operations.

The vessels have a separate deck for the clients' use, with cabins and offices and a separate data network. The high quality facilities accommodate a total of 45-47 guests, depending on the ship.

Fennica

Dimensions
Length	116.00 m
Beam	26.00 m
Draught	8.40 m max.
Built	1993
Max. speed	16 knots

Class
DnV + 1A1 – Tug Supply Vessel – SF – EO – Icebreaker polar – 10, Dynpos, AUTR, Helideck

Dynpos
Simrad ADP 702

Accommodation
82 persons
24 cabins for client use (47 persons)
Client's offices: 1 operation centre on 4th bridge deck, 1 x 20 m² office

Helideck
Superpuma or similar

Deck
Working deck area 1090 m²
Anchor handling/winch
Aquamaster TAW 3000/3000 E

Machinery
Main engines
2 x Wärtsilä Diesel, Vasa 16V 32, each 6000 kW
2 x Wärtsilä Diesel, Vasa 12V 32, each 4500 kW
Generators
ABB Strömberg Drives
2 x HSG 1120 MP8, power 8.314 kVA, Volt 6.3 KV, speed750 rpm
2 x HSG 900 LR8, power 6.235 kVA, Volt 6.3 KV, speed 750 rpm
Propellers
2 x HSSOL 18/1654, output 7.500 kW each, ABB Strömberg Drives
2x Aquamater-Rauma US ARC 1, 7500 kW each,
FP propellers, variable RPM
Bow thrusters
3 x Brunvoll FV-80 LTC-2250, VP propellers 1.050 kW each

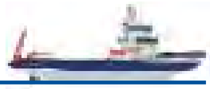
Bollard pull 234 tons

Crane(s) (optional)
Stb	30 tons/38 metre jib
Port	15 tons
A-frame	120 tons

Navigation Equipment
Robertson ECDIS Navigation System
Doppler speed log
Loran C
GPS
Fiber optic gyros
Differential GPS Gyro.
Navintra Ecdis
Direction finder
Echo sounder
Facsimile recorder

Communication Equipment
1 x Skanti TRP 8400D MF/HF SSB, including all GMDSS requirements
1 x Watch receiver
1 x Aero VHF. Helicopter communication
6 x VHF
1 x Navtex receiver
1 x Inmarsat B satellite comm. system
VSAT online satellite comm. system
3 x UHF walkie-talkie
3 x VHF walkie-talkie
2 x Freefloat EPRIB, 121,5 and 406 MHz
2 x Distress transponders, 96 Hz
Call signal OJAD

Nordica



Dimensions
Length	116.00 m
Beam	26.00 m
Draught	8.40 m max.
Built	1994
Max. speed	16 knots

Class
DnV + 1A1 – Tug Supply Vessel – SF – EO – Icebreaker polar – 10, Dynpos, AUTR, Helideck

Dynpos
Simrad ADP 702

Accommodation
82 persons
24 cabins for client use (47 persons)
Client's offices: 1 operation centre on 4th bridge deck, 1 x 20 m² office

Helideck
Superpuma or similar

Deck
Working deck area 1090 m²
Anchor handling/towing winch
Aquamaster TAW 3000/3000 E

Machinery
Main engines
2 x Wärtsilä Diesel, Vasa 16V 32, each 6000 kW
2 x Wärtsilä Diesel, Vasa 12V 32, each 4500 kW
Generators
ABB Strömberg Drives
2 x HSG 1120 MP8, power 8.314 kVA, Volt 6.3 KV, speed750 rpm
2 x HSG 900 LR8, power 6.235 kVA, Volt 6.3 KV, speed 750 rpm
Propellers
2 x HSSOL 18/1654, output 7.500 kW each, ABB Strömberg Drives
2x Aquamater-Rauma US ARC 1, 7500 kW each,
FP propellers, variable RPM
Bow thrusters
3 x Brunvoll FV-80 LTC-2250, VP propellers 1.050 kW each

Bollard pull 234 tons

Main crane (optional)

Lifting capacity	160 T/9 m 30 T/32 m
Main winch	Active Heave Compensated Constant Tension
Heave amplitude	+ 3,5 m double part + 7 m single part
Operating depth	500 m–160 T (double part) 1000 m–80 T (single part)
Aux winch	10 T, 33 m, Constant Tension
Tugger winches	2 x 4 T Constant Tension
Port	15 tons

A-frame (optional) 120 tons

Navigation Equipment
Navintra ECDIS Navigation System
Doppler speed log
Loran C
GPS
Fiber Optic Gyros
Differential GPS Gyro.
Direction finder
Echo sounder
Facsimile recorder

Communication Equipment
1 x Skanti TRP 8400D MF/HF SSB, including all GMDSS requirements
1 x Watch receiver
1 x Aero VHF. Helicopter communication
6 x VHF
1 x Navtex receiver
1 x Inmarsat B satellite comm. system
VSAT online satellite comm. system
3 x UHF walkie-talkie
3 x VHF walkie-talkie
2 x Freefloat EPRIB, 121,5 and 406 MHz
2 x Distress transponders, 96 Hz
Call signal OJAE

Botnica

Dimensions
Length	96.70 m
Beam	24.00 m
Draught	7.2 to 8.5 m
Built	1998
Max. speed	15 knots

Class
DnV + 1A1 – Supply Vessel – SF – EO – Icebreaker Ice – 10,
Dynpos AUTRO, RPS
NMD Mobile offshore Units, DP UNIT, with equipment class 3

Dynpos
Simrad SDP22 + SDP12 backup
2 x HIPAP combined SSBL/MULBL hydroacoustic system
2 x Seatex DPS DGPS combined GPS/Glonass

Accommodation
72 persons
24 cabins for client use (45 pers.)
2 x client's office

Helideck
Superpuma or similar

Deck
Working deck area 1000 m²

Machinery
Main engines
12 x Caterpillar 3512B, 1257 kW, 1500 rpm
Main generators
6 x ABB-AMG 560, 2850 kVA, 3,3 kV 3 N, 50 Hz
Emergency generators
1 x Caterpillar 3406, 200 kW, 400 V, 3 N, 50 Hz
Main propulsion
Stern 2 x 5000 kW Azipod, FP
Bow thrusters
3 x Brunvol tunnel, variable pitch á 1150 kW

Bollard pull 117 tons

Crane(s) (optional)
1 x Hydralift, 160 tons
1 x 15 tons

Main cranes
Lifting capacity	160 T/9 m 30 T/32 m
Main winch	Active Heave Compensated Constant Tension
Heave amplitude	+ 4 m double part + 8 m single part
Operating Depth	550 m–160 T (double part) 1100 m– 80 (single part)
Aux winch	10 T, 33 m, Constant Tension

Moonpool 6.5 x 6.5 metres

Navigation and communication equipment
GMDSS
Inmarsat B
VSAT online satellite comm. system
Call signal OJAK

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e-mail: maritime@gdv.no
www.gdv.no

2. SUMMARY OF RESULTS

A summary of the NO_x test results are presented in Table 2-1.

Table 2-1 Summary of NO_x Emissions

Run	Load %	Load kW	NO_x dppmv	NO_x lb/hr	NO_x* Lb/kW-hr
1	35	2100	738.7	51.0	0.0243
2			718.8	48.5	0.0231
3			713.6	47.5	0.0226
Average			**723.7**	**49.0**	**0.0233**
4	57	3480	598.3	61.4	0.0177
5			675.4	69.3	0.0199
6			656.7	69.0	0.0198
Average			**643.5**	**66.6**	**0.0191**
7	80	4800	752.9	97.9	0.0204
8			720.2	92.3	0.0192
9			746.2	99.3	0.0207
Average			**739.8**	**96.5**	**0.0201**

*Based on Methods 2 – 4

A more detailed summary of results is provided in Appendix A. The field data is presented Appendix C.

3. DESCRIPTION OF THE SOURCE

Source Group C1 includes two, identical Wartsila 16V32 main propulsion engines rated at 7884 hp (6000 kW); Unit IDs FN-1 and FN-2.

4. DESCRIPTION OF THE SAMPLE LOCATIONS

The Wartsila 16V32 main propulsion engine exhausts into a vertical, circular stack with an internal diameter of 31.5 inches. The stack is equipped with two ¾ -inch sample ports located approximately 10 feet (3.8 stack diameters) downstream and approximately 3 feet upstream of the nearest flow disturbance.

Mr. Hudson chose a 16 point velocity traverse, 8 points per port. Please refer to Table 4-1 for selected velocity traverse points.

Run Number			1	2	3	4	5	6	7	8	9
Run Start Time			346	500	612	723	841	957	1225	1400	1524
Load		kW	2100	2100	2100	3480	3480	3480	4800	4800	4800
Load		%	35%	35%	35%	57%	57%	57%	80%	80%	80%
DGM Volume	V_m	cubic feet	27.063	25.790	21.435	25.691	25.280	25.093	31.698	21.868	23.050
DGM Y Factor	Y	-	1.002	1.002	1.002	1.002	1.002	1.002	1.002	1.002	1.002
DGM Average Temperature	T_m	Degrees R	535	538.5	543	545	543	547	545.5	548.5	551.5
Barometric Pressure	P_{bar}	Inches Hg	30.15	30.15	30.15	31.30	31.13	31.15	31.13	31.16	31.16
Delta H	ΔH	Inches Water	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6
Sample Volume at Standard Conditions	V_{mstd}	Standard	26.997	25.560	21.067	26.116	25.653	25.293	32.018	21.989	23.052
Total Volume of Water collected	V_{lc}	Milliliters	34.9	35.6	31.6	24.7	52.9	37.6	35.4	33.1	15.3
Standard Volume of Water	V_{wstd}	Standard Cubic	1.642	1.675	1.487	1.162	2.489	1.769	1.666	1.558	0.720
Stack Gas Moisture Content	B_{ws}	-	0.0573	0.0615	0.0659	0.0426	0.0885	0.0654	0.0495	0.0662	0.0303
Pitot Tube Coefficient	C_p	-	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99
Average Pitot differential pressure	ΔP	Inches Water	0.48	0.47	0.46	1.0	1.1	1.1	1.7	1.7	1.7
Square Root of Differential Pressure		-	0.693	0.686	0.678	1.000	1.049	1.049	1.304	1.304	1.304
Average Stack Gas Temperature	$T_{s(ave)}$	Degrees R	1135	1152	1152	1136	1141	1142	1183	1183	1171
Measured Stack Pressure	P_q	Inches Water	0.1	0.1	0.1	0.15	0.15	0.15	0.15	0.15	1.5
Absolute Stack Pressure	P_s	Inches Hg	30.2	30.2	30.2	31.3	31.1	31.2	31.1	31.2	31.3
Stack $\%O_2$		%	13.56	13.60	13.59	13.44	13.32	13.37	12.49	12.64	12.57
Stack $\%CO_2$		%	5.4	5.4	5.4	5.7	6.9	5.5	6.2	6.2	6.2
Stack $\%N_2$ + %CO		%	81.0	81.0	81.0	80.9	79.8	81.1	81.4	81.1	81.2
Stack Gas Dry Molecular Weight	M_d		29.4	29.4	29.4	29.4	29.6	29.4	29.5	29.5	29.5
Stack Gas Wet Molecular Weight	M_s	lb/lb mole	28.76	28.71	28.66	28.96	28.61	28.67	28.92	28.74	29.15
Actual Average Velocity	V_s	ft/sec	67.07	66.92	66.26	94.73	100.45	100.35	126.47	126.79	125.07
Stack Diameter		ft	2.63	2.63	2.63	2.63	2.63	2.63	2.63	2.63	2.63
Stack Area	A	sq ft	5.41	5.41	5.41	5.41	5.41	5.41	5.41	5.41	5.41
Standard Stack Gas Volumetric Flow	Q_{sd}	Standard Dry Cubic Feet/min	9626.6	9421.2	9284.6	14323.6	14319.5	14663.9	18133.2	17877.3	18558.5
NOx dry volumetric concentration	$C_{d(NOx)}$	dppmv	738.7	718.8	713.6	598.3	675.4	656.7	752.9	720.2	746.2
NOx as NO2	$E_{(NOx)}$	lb/hr	51.0	48.5	47.5	61.4	69.3	69.0	97.9	92.3	99.3
Fuel Consumption		gal/hr	107	107	107	165	165	165	227	227	227
Fuel Consumption		MMbtu/hr	14.91	14.91	14.91	22.99	22.99	22.99	31.62	31.62	31.62
NOx emissions		lb/gal	0.476	0.454	0.444	0.372	0.420	0.418	0.431	0.407	0.437
NOx emissions		g/bhp-hr	8.225	7.832	7.663	5.981	6.750	6.721	6.908	6.515	7.007
NOx emissions		lb/kW-h	0.0243	0.0231	0.0226	0.0177	0.0199	0.0198	0.0204	0.0192	0.0207
NOx emissions (M19)		lb/hr	34.40	33.66	33.37	42.28	46.97	45.97	64.93	63.24	64.97
NOx emissions (M19)		lb/gal	0.32	0.31	0.31	0.26	0.28	0.28	0.29	0.28	0.29
NOx emissions (M19)		lb/mmBTU	2.31	2.26	2.24	1.84	2.04	2.00	2.05	2.00	2.05

Tor Viking II

Function: Secondary Icebreaker

Ship Dimensions
Length: 83.7 m
Width: 18.0 m
Propulsion: (2) MaK 8M32C (3,840 kW each)
(2) MaK 6M32C (2,880 kW each)
Reference: Vessel Specifications

Stack Parameters (propulsion engines)
Height: 28.96 m
Diameter: 0.70 m
Velocity: 24.9 m/sec @ 80% load
Temperature: 579 K @ 80% load
References: Stack test - 5/18/2007

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15.12.2008 15:41:58
The partners in Trans Viking agree to divide ownership

19.11.2008 21:32:53
Sponsoring the local rescue service

08.09.2008 13:45:56
Viking scores high on FPAL

04.07.2008 10:07:49
Vessels being fitted with new secondary winches

News Archive

AHTS/Icebreaker Tor Viking II - Main Characteristics

Design :
KMAR 808 AHTS/ ICEBREAKER (Now; MOSSMAR)

Classification :
DnV,+1A1, TUG/SUPPLY VESSEL, SF, EO, ICEBREAKER ICE-10, HELDK-SH, WI-OC DK(+), HK(2.8), DYNPOS-AUTR (DP-Green)

Built / Delivered :
Havyard Leirvik, Norway - 03/2000 - IMO 9199622

Flag / Registered :
Swedish / Skärhamn

Owners :
Trans Viking Icebreaking & Offshore AS , Kristiansand, Norway

Commercial Managers :
Viking Supply Ships A/S, Kristiansand, Norway

Dimensions
Length Over All (LOA) : 83.70 metres
Length between p.p. : 75.20 metres
Breadth, moulded : 18.00 metres
Depth, moulded : 8.50 metres
Draught (scantling) : 7.20 metres
Draught (design) : 6.00 metres
Freeboard (design) : 2.50 metres

Tonnage
Dead Weight : 2,528 tonnes
Light Ship : 4,289 tonnes
Gross : 3,382 tonnes
Net : 1,145 tonnes

Capacities
Dry Bulk : 283 m 3 in 4 tanks - totalling 10,000 ft 3
Pot Water : 724 m 3
Drill Water / Ballast : 1,113 m 3
Brine : 400 m 3 – SG 2.5
Oil Based Mud : 657 m 3 – SG 2.8
Base Oil : 242 m 3
Fuel Oil : 1,190 m 3 Marine Gas Oil (Diesel)
Urea : 94 m 3
Diesel Overflow : 21 m 3 with alarm
Diesel Service / Settling : 2 x 20 m 3
Deck Load : Abt 1,350 ts
Deck Area : 603 m 2 / 40.20 m x 15.0 m
All products in dedicated tanks – no dual purpose tanks

Discharge Rates / Lines etc.
Dry Bulk : 2 x 25 m 3/h compressors – 80 psi. Two separate discharge systems.
Discharge rate 2 x 75 m 3 / h at 90 metres head
Pot Water : Discharge rate 1 x 250 m 3 / h at 9 bar
Drill Water / Ballast : Discharge rate 1 x 250 m 3 / h at 9 bar
Brine : Discharge rate 2 x 75 m 3 / h at 18 bar
Oil Based Mud : Discharge rate 2 x 75 m 3 / h at 24 bar - Oil Mud Agitators fitted
Base Oil : Discharge rate 1 x 75 m 3 / h at 9 bar
Fuel Oil (Diesel) : Discharge rate 1 x 250 m 3 / h at 9 bar
Discharge Stations : All products mid and aft both SB and PS
Discharge Lines : 6 inch Weco system with reducers for Pot / Drill Water, Fuel Oil and Dry Bulk
: 5 inch Weco system with reducers for Brine, Base Oil and Oil Base Mud
Tank cleaning : Mud and Base Oil tanks fitted with permanent tank cleaning system and heating
Flow Meters : Flow meters fitted for Pot Water and Fuel Oil (Digital display + printer for MGO)

Propulsion
Main Engine : MAK 18,300 BHP - 4 eng (father/son) 2 x 3,840 kW + 2 x 2,880 kW = 13,440 kW
Thrusters : Bow 1,200 BHP in tunnel (Electr) + 1,200 BHP 360 deg retractable = 2,400 BHP
: Stern 1,200 BHP in tunnel (Electrical)
Propellers : 2 KaMeWa 4 blades in nozzles – dia abt 4.0 meter
Rudders : 2 spade rudders

Bollard Pull
Bollard Pull : 202 continuous (DnV certified) / Abt 210 max pull

Speed/Consumption
Speed/Consumption : 16 knots – Abt. 42.7 MT / 24 hrs at 6.0 meter draught
12 knots – Abt. 15.6 MT
10 knots – Abt. 8.6 MT

Towing & Anchorhandling Equipment
AHT Winch : Brattvaag towing/anchorhandling winch 400 ts pull / 550 ts brake holding cap

CONTACT US

Viking Supply Ships AS
Kirkegaten 1
P.O Box 204
N - 4662 KRISTIANSAND
NORWAY

Ph: **+47 38 12 41 70**

AHT Drum : One of 1,400 mm dia. x 3,750 dia x (1,250 mm + 1,250 mm) length
Wire Capacity : 2 x 1,900 m of 77 mm wire or 2 x 1,650 m of 83 mm wire
AH Drum : One of 1,400 mm dia. x 3,750 mm dia. x 3,000 mm length
Wire Capacity : 4,100 m of 83 mm wire
Winch Control : TOWCON 2000 Aut. Control with printer
Secondary Winch: One off 1600 m of 203 mm synthetic rope
Barrel length 4200 mm + 2 x 1100 mm socket compartments

Spooling device :
Work / Towing drums arranged according to latest NMD requirements
Cable Lifters : 2 x 76 mm and 2 x 84 mm onboard
Chain Lockers : 2 x 127 m 3 / giving abt 2 x 6,000 ft of 3 inch chain
Shark Jaws : 2 sets of Karm Forks arranged for chain up to 165 mm dia / 750 ts SWL
Inserts for handling 65, 75, 85, 100, and 120 mm dia. wire/chain
: Forks arranged with alarm system acc to latest NMD requirements
Stern Roller : One of 3,5 m dia. x 6.0 m length – SWL 500 ts
Guide Pins : 2 pairs of Karm Fork Hydraulic pins – SWL 170 ts

Workwires
Work Wire : 300 metres of 77 mm dia
Chase Wire : 1,000 metres of 83 mm dia
Main Tow Wire : 1,500 metres of 83 mm dia
Spare Tow Wire : 1,300 metres of 83 mm dia

Deck Equipment
Capstans : 2 x 15 ts pull
Tugger Winches : 2 x 15 ts pull
Smit Brackets : One bracket on B Deck FW – SWL 250 ts
Cranes : 1 hydraulic crane on forep cargo deck giving 6 / 12 ts at 20/10 m arm (360 degr)
: 1 telescopic crane on aft cargo deck giving 1.5 / 3 ts at 15/10 m arm (360 degr)
: 1 hydraulic crane on fore-castle deck for stores etc
Windlass : 1 hydraulic windlass / mooring winch. Two de-clutch able drums 46 mm K3 chain

Accommodation
Accommodation for a total of 23 persons, including crew
All accommodation equipped with air-condition and humidification facilities.

Misc.
We would like to highlight the exceptional good manoeuvrability of the vessel. Also please note the environmental bonus using "Tor Viking II" due to her exceptional low noise level, and the installed Exhaust Gas Treatment Systems (Catalyst), effectively reducing the NOx levels. "Tor Viking II" is also equipped with diesel overflow tank with alarm system. The vessels design, and her possibility for running 2 engines, ("father/son") gives very favourable fuel consumption.
Spooling Devizes and DynPos 2 – Kongsberg Simrad SDP21 – "DP Green" system were installed in May 2003

Particulars believed to be correct, without guarantee.

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Table 2.1.1

Summary of Average NO_x Results

MaK 8M32 Main Propulsion Engine/Generator (Main Engine #2)
Unit TV-2, Source Group C1
May 18-19, 2007

Shell Offshore, Inc.
Kulluk Drilling Unit (Kulluk)
Norway

SCR ON						
Method	**Pollutant**	**Emission Unit**	**Run #**			**Average**
LOAD CONDITION – 80%			1	2	3	
Diesel Fuel Useage	---	L/hr	601	604	498	**568**
Method 7E	**NO_x**	ppm	190.8	200.8	223.5	**205.0**
	NO_x	lb/hr	13.3	13.7	14.4	**13.8**
	NO_x	lb/MMBtu	0.5913	0.6223	0.7021	**0.6386**
	NO_x	lb/gal	0.0836	0.0860	0.1093	**0.0929**
LOAD CONDITION – 57%			4	5	6	
Diesel Fuel Useage	---	L/hr	389	387	390	**389**
Method 7E	**NO_x**	ppm	92.3	94.7	96.0	**94.3**
	NO_x	lb/hr	5.04	5.17	5.28	**5.16**
	NO_x	lb/MMBtu	0.2900	0.2975	0.3058	**0.2977**
	NO_x	lb/gal	0.0490	0.0505	0.0512	**0.0503**
LOAD CONDITION – 35%			7	8	9	
Diesel Fuel Useage	---	L/hr	207	209	210	**209**
Method 7E	**NO_x**	ppm	95.8	93.8	78.3	**89.3**
	NO_x	lb/hr	2.84	2.77	2.22	**2.61**
	NO_x	lb/MMBtu	0.3010	0.2947	0.2460	**0.2805**
	NO_x	lb/gal	0.0519	0.0502	0.0399	**0.0473**

TRC Environmental Corp.

EMISSION MEASUREMENTS DEPARTMENT

19874 141st Place N.E.
Woodinville, WA 98072
Phone: (425) 489-1938
Fax: (425) 489-9564

CLIENT:	Shell Offshore, Inc. - Norway	DATES:	5/18/2007
LOCATION:	Tor Viking II	PROJECT NO.:	150614
UNIT:	Main Engine #2 (SCR On)	PERSONNEL:	MM/PJC/JT
CONDITION:	80% Load		

Data Input Sheet

The table below contains the results of testing and calculations performed by TRC on the date(s) listed.

Moisture & Airflow

Parameter	SYMBOL	UNITS	DATA			
Test Number			Run 1	Run 2	Run 3	
Test Date			5/18/2007	5/18/2007	5/18/2007	
Method 4 Start Time			1553	1708	1821	
Method 4 Stop Time			1653	1808	1921	**3-RUN AVG.**
Stack Diameter	ds	inches	27.5	27.5	27.5	
Barometric Pressure at Sampling Location	Pbar	in. Hg	29.90	29.96	29.90	29.92
Stack Static Pressure	Pg	in. H_2O	1.05	1.05	1.15	1.08
Pitot Coefficient	cp	none	0.84	0.84	0.84	
Meter Calibration Factor	Y	none	0.976	0.976	0.976	
	DH@	none	1.678	1.678	1.678	
Stack Gas Oxygen Content	O_2	%	13.5	13.5	13.6	13.5
Stack Gas Carbon Dioxide Content	CO_2	%	5.6	5.6	5.6	5.6
Net Moisture Gain (Impingers w/SiGel)	Ww	grams	206.0	206.0	206.0	206.0
Average Stack Temperature	ts	deg F	582.5	580.4	587.0	583.3
Average Meter Temperature	tm	deg F	68.8	70.3	72.4	70.5
Avg Delta H	dH	in. H_2O	1.00	1.00	1.00	1.00
Average Square Root Delta H	ASR dH	in. H_2O	1.000	1.000	1.000	1.000
Avg Velocity Head	dP	in. H_2O	1.15	1.11	0.99	1.08
Average Square Root Delta P	ASR dP	in. H_2O	1.063	1.042	0.985	1.030
Gas Sample Volume	Vm	cu. ft.	36.816	36.710	35.742	36.423
Total Sampling Time	min	minutes	60	60	60	

TRC Environmental Corp. EMISSION MEASUREMENTS DEPARTMENT

19874 141st Place N.E.
Woodinville, WA 98072
Phone: (425) 489-1938
Fax: (425) 489-9564

CLIENT:	Shell Offshore, Inc. - Norway	DATES:	5/18/2007
LOCATION:	Tor Viking II	PROJECT NO.:	150614
UNIT:	Main Engine #2 (SCR On)	PERSONNEL:	MM/PJC/JT
CONDITION:	80% Load		

Calculation Sheet

The table below contains the results of testing and calculations performed by TRC on the date(s) listed.

Moisture & Airflow

Parameter	SYMBOL	UNITS	DATA			
Test Number			Run 1	Run 2	Run 3	
Test Date			5/18/2007	5/18/2007	5/18/2007	
Method 4 Start Time:			1553	1708	1821	
Method 4 Stop Time:			1653	1808	1921	
Calculated Data						**3-RUN AVG.**
Stack Area,As=3.14159*((Ds/12)/2)^2	As	sq.ft.	4.12	4.12	4.12	4.12
Avg Stack Temperature, Ts=ts+460	Ts	deg R	1042.5	1040.4	1047.0	1043.3
Meter Pressure, Pm=Pb+Dh/13.6	Pm	in. Hg	29.97	30.03	29.97	29.99
Avg Meter Temperature, Tm=tm+460	Tm	deg R	528.8	530.3	532.4	530.5
Gas Sample Volume at Standard Conditions,	Vm(std)	cu. ft.	35.943	35.810	34.661	35.471
Vm(std)= 528/29.92*Y*Vm*Pm/Tm		cu. m.	1.018	1.014	0.981	1.004
Net Moisture Gain (Impingers w/SiGel)	Ww	mL	206.0	206.0	206.0	206.0
Volume of Water Vapor, Vw(std)= 0.04715*Wlc	Vw(std)	cu. ft.	9.713	9.713	9.713	9.713
Moisture Fraction, Bws = Vw(Std)/(Vm(Std)+Vw(Std))*100	Bws	%	8.36%	8.36%	8.36%	8.36%
Dry Stack Gas Molecular Weight, Md = (0.32*O2)+(0.44*CO2)+(0.28*(100-(O2+CO2)))	Mwd	g/g-mole	29.44	29.44	29.44	29.44
Wet Stack Gas Molecular Weight Mw = Md* (1-Bws)+(18*(Bws))	Mws	g/g-mole	28.48	28.48	28.48	28.48
Absolute Stack Pressure, Ps = Pbar + Pg/13.6	Ps	in. Hg.	29.98	30.04	29.98	30.00
Stack Gas Velocity Vs= 85.49*Cp*ASRdP*((Ts)/((Ps)*(Mw)))^0.5	Vs	ft/sec	84.39	82.52	78.32	81.74
Vsm = 0.3048* Vs	Vsm	m/sec	25.72	25.15	23.87	24.92
Actual Stack Gas Flow Rate, Qa = 60*Vs*As	Qa	acf/min	20,884.2	20,423.0	19,382.6	20,229.9
Stack Gas Flow Rate (STP), Qsw = 528/29.92 * Qa * (Ps/Ts)	Qsw	scf/min	10,597.3	10,405.2	9,796.0	10,266.1
Dry Stack Gas Flow Rate (Dry, STP),	Qsd	dscf/min	9,710.9	9,534.9	8,976.6	9,407.5
Qsd = 528/29.92 * Qa * (1-Bws)* (Ps/Ts)		dscm/min	274.9	269.9	254.1	266.3

Sampling Data Summary

Parameter	SYMBOL	UNITS	Run 1	Run 2	Run 3	3-RUN AVG.
Total Sampling Time	min	minutes	60	60	60	60
Stack Gas Oxygen Content	O_2	%	13.5	13.5	13.6	13.5
Stack Gas Carbon Dioxide Content	CO_2	%	5.6	5.6	5.6	5.6
Gas Sample Volume at Standard Conditions,	Vm(std)	cu. ft.	35.943	35.810	34.661	35.471
		cu. m.	1.018	1.014	0.981	1.004
Dry Stack Gas Flow Rate (Dry, STP),	Qsd	dscf/min	9,710.9	9,534.9	8,976.6	9,407.5
		dscm/min	274.9	269.9	254.1	266.3

TRC Environmental Corp.

EMISSION MEASUREMENTS DEPARTMENT

19874 141st Place N.E.
Woodinville, WA 98072
Phone: (425) 489-1938
Fax: (425) 489-9564

CLIENT:	Shell Offshore, Inc. - Norway	DATES:	5/18/2007
LOCATION:	Tor Viking II	PROJECT NO.:	150614
UNIT:	Main Engine #2 (SCR On)	PERSONNEL:	MM/MLE
CONDITION:	57% Load		

Data Input Sheet

The table below contains the results of testing and calculations performed by TRC on the date(s) listed.

Moisture & Airflow

Parameter	SYMBOL	UNITS	DATA			
Test Number			Run 4	Run 5	Run 6	
Test Date			5/18/2007	5/18/2007	5/18/2007	
Method 4 Start Time			1835	2100	2215	
Method 4 Stop Time			2035	2200	2315	3-RUN AVG.
Stack Diameter	ds	inches	27.5	27.5	27.5	
Barometric Pressure at Sampling Location	Pbar	in. Hg	29.90	29.90	29.90	29.90
Stack Static Pressure	Pg	in. H_2O	-0.15	-0.15	-0.15	-0.15
Pitot Coefficient	cp	none	0.84	0.84	0.84	
Meter Calibration Factor	Y	none	0.976	0.976	0.976	
	DH@	none	1.678	1.678	1.678	
Stack Gas Oxygen Content	O_2	%	13.6	13.6	13.7	13.6
Stack Gas Carbon Dioxide Content	CO_2	%	5.5	5.5	5.5	5.5
Net Moisture Gain (Impingers w/SiGel)	Ww	grams	182.0	182.0	182.0	182.0
Average Stack Temperature	ts	deg F	632.8	633.0	633.0	632.9
Average Meter Temperature	tm	deg F	71.2	69.5	75.0	71.9
Avg Delta H	dH	in. H_2O	1.00	1.00	1.00	1.00
Average Square Root Delta H	ASR dH	in. H_2O	1.000	1.000	1.000	1.000
Avg Velocity Head	dP	in. H_2O	0.72	0.72	0.73	0.73
Average Square Root Delta P	ASR dP	in. H_2O	0.849	0.849	0.856	0.851
Gas Sample Volume	Vm	cu. ft.	36.499	35.985	36.099	36.194
Total Sampling Time	min	minutes	60	60	60	

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CLIENT:	Shell Offshore, Inc. - Norway	DATES:	5/18/2007
LOCATION:	Tor Viking II	PROJECT NO.:	150614
UNIT:	Main Engine #2 (SCR On)	PERSONNEL:	MM/MLE
CONDITION:	57% Load		

Calculation Sheet

The table below contains the results of testing and calculations performed by TRC on the date(s) listed.

Moisture & Airflow

Parameter	SYMBOL	UNITS	DATA			
Test Number			Run 4	Run 5	Run 6	
Test Date			5/18/2007	5/18/2007	5/18/2007	
Method 4 Start Time:			1835	2100	2215	
Method 4 Stop Time:			2035	2200	2315	
Calculated Data						**3-RUN AVG.**
Stack Area,As=3.14159*((Ds/12)/2)^2	As	sq.ft.	4.12	4.12	4.12	4.12
Avg Stack Temperature, Ts=ts+460	Ts	deg R	1092.8	1093.0	1093.0	1092.9
Meter Pressure, Pm=Pb+Dh/13.6	Pm	in. Hg	29.97	29.97	29.97	29.97
Avg Meter Temperature, Tm=tm+460	Tm	deg R	531.2	529.5	535.0	531.9
Gas Sample Volume at Standard Conditions,	Vm(std)	cu. ft.	35.471	35.085	34.834	35.130
Vm(std)= 528/29.92*Y*Vm*Pm/Tm		cu. m.	1.004	0.993	0.986	0.995
Net Moisture Gain (Impingers!)	Ww	mL	146.0	146.0	146.0	146.0
Net Moisture Gain (Impinger w/SiGel)	Ww	grams	36.0	36.0	36.0	36.0
Volume of Water Vapor, Vw(std)= 0.04715*Wlc	Vw(std)	cu. ft.	8.581	8.581	8.581	8.581
Moisture Fraction, Bws = Vw(Std)/(Vm(Std)+Vw(Std))*100	Bws	%	7.53%	7.53%	7.53%	7.53%
Dry Stack Gas Molecular Weight, Md = (0.32*O2)+(0.44*CO2)+(0.28*(100-(O2+CO2)))	Mwd	g/g-mole	29.42	29.42	29.43	29.43
Wet Stack Gas Molecular Weight Mw = Md* (1-Bws)+(18*(Bws))	Mws	g/g-mole	28.56	28.56	28.57	28.57
Absolute Stack Pressure, Ps = Pbar + Pg/13.6	Ps	in. Hg.	29.89	29.89	29.89	29.89
Stack Gas Velocity Vs= 85.49*Cp*ASRdP*((Ts)/((Ps)*(Mw)))^0.5	Vs	ft/sec	68.97	68.96	69.51	69.15
Vsm = 0.3048* Vs	Vsm	m/sec	21.02	21.02	21.19	21.08
Actual Stack Gas Flow Rate, Qa = 60*Vs*As	Qa	acf/min	17,069.2	17,065.4	17,202.4	17,112.3
Stack Gas Flow Rate (STP), Qsw = 528/29.92 * Qa * (Ps/Ts)	Qsw	scf/min	8,239.0	8,235.5	8,301.2	8,258.6
Dry Stack Gas Flow Rate (Dry, STP),	Qsd	dscf/min	7,618.7	7,615.4	7,676.1	7,636.8
Qsd = 528/29.92 * Qa * (1-Bws)* (Ps/Ts)		dscm/min	215.7	215.6	217.3	216.2

Sampling Data Summary

Parameter	SYMBOL	UNITS	Run 4	Run 5	Run 6	3-RUN AVG.
Total Sampling Time	min	minutes	60	60	60	60
Stack Gas Oxygen Content	O_2	%	13.6	13.6	13.7	13.6
Stack Gas Carbon Dioxide Content	CO_2	%	5.5	5.5	5.5	5.5
Gas Sample Volume at Standard Conditions,	Vm(std)	cu. ft.	35.471	35.085	34.834	35.130
		cu. m.	1.004	0.993	0.986	0.995
Dry Stack Gas Flow Rate (Dry, STP),	Qsd	dscf/min	7,618.7	7,615.4	7,676.1	7,636.8
		dscm/min	215.7	215.6	217.3	216.2

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CLIENT:	Shell Offshore, Inc. - Norway	DATES:	5/18-19/2007
LOCATION:	Tor Viking II	PROJECT NO.:	150614
UNIT:	Main Engine #2 (SCR On)	PERSONNEL:	MM/MLE
CONDITION:	35% Load		

Data Input Sheet

The table below contains the results of testing and calculations performed by TRC on the date(s) listed.

Moisture & Airflow

Parameter	SYMBOL	UNITS	DATA			
Test Number			Run 7	Run 8	Run 9	
Test Date			5/18-19/2007	5/19/2007	5/19/2007	
Method 4 Start Time			2330	0045	0200	
Method 4 Stop Time			2430	0145	0300	**3-RUN AVG.**
Stack Diameter	ds	inches	27.5	27.5	27.5	
Barometric Pressure at Sampling Location	Pbar	in. Hg	29.90	29.90	29.90	29.90
Stack Static Pressure	Pg	in. H_2O	-0.18	-0.18	-0.18	-0.18
Pitot Coefficient	cp	none	0.84	0.84	0.84	
Meter Calibration Factor	Y	none	0.976	0.976	0.976	
	DH@	none	1.678	1.678	1.678	
Stack Gas Oxygen Content	O_2	%	13.6	13.6	13.6	13.6
Stack Gas Carbon Dioxide Content	CO_2	%	5.6	5.6	5.6	5.6
Net Moisture Gain (Impingers w/SiGel)	Ww	grams	143.0	143.0	143.0	143.0
Average Stack Temperature	ts	deg F	674.7	675.1	674.6	674.8
Average Meter Temperature	tm	deg F	67.6	75.1	76.4	73.0
Avg Delta H	dH	in. H_2O	1.00	1.00	1.80	1.27
Average Square Root Delta H	ASR dH	in. H_2O	1.000	1.000	1.342	1.114
Avg Velocity Head	dP	in. H_2O	0.21	0.21	0.20	0.21
Average Square Root Delta P	ASR dP	in. H_2O	0.461	0.460	0.441	0.454
Gas Sample Volume	Vm	cu. ft.	35.090	35.797	48.330	39.739
Total Sampling Time	min	minutes	60	60	60	

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CLIENT:	Shell Offshore, Inc. - Norway	DATES:	5/18-19/2007
LOCATION:	Tor Viking II	PROJECT NO.:	150614
UNIT:	Main Engine #2 (SCR On)	PERSONNEL:	MM/MLE
CONDITION:	35% Load		

Calculation Sheet

The table below contains the results of testing and calculations performed by TRC on the date(s) listed.

Moisture & Airflow

Parameter	SYMBOL	UNITS	DATA			
Test Number			Run 7	Run 8	Run 9	
Test Date			5/18-19/2007	5/19/2007	5/19/2007	
Method 4 Start Time:			2330	0045	0200	
Method 4 Stop Time:			2430	0145	0300	
Calculated Data						**3-RUN AVG.**
Stack Area,As=3.14159*((Ds/12)/2)^2	As	sq.ft.	4.12	4.12	4.12	4.12
Avg Stack Temperature, Ts=ts+460	Ts	deg R	1134.7	1135.1	1134.6	1134.8
Meter Pressure, Pm=Pb+Dh/13.6	Pm	in. Hg	29.97	29.97	30.03	29.99
Avg Meter Temperature, Tm=tm+460	Tm	deg R	527.6	535.1	536.4	533.0
Gas Sample Volume at Standard Conditions,	Vm(std)	cu. ft.	34.332	34.533	46.609	38.492
Vm(std)= 528/29.92*Y*Vm*Pm/Tm		cu. m.	0.972	0.978	1.320	1.090
Net Moisture Gain (Impingers)	Ww	mL	119.0	119.0	119.0	119.0
Net Moisture Gain (Impinger w/SiGel)	Ww	grams	24.0	24.0	24.0	24.0
Volume of Water Vapor, Vw(std)= 0.04715*Wlc	Vw(std)	cu. ft.	6.742	6.742	6.742	6.742
Moisture Fraction, Bws = Vw(Std)/(Vm(Std)+Vw(Std))*100	Bws	%	5.52%	5.52%	5.52%	5.52%
Dry Stack Gas Molecular Weight, Md = (0.32*O2)+(0.44*CO2)+(0.28*(100-(O2+CO2)))	Mwd	g/g-mole	29.44	29.44	29.44	29.44
Wet Stack Gas Molecular Weight Mw = Md* (1-Bws)+(18*(Bws))	Mws	g/g-mole	28.81	28.81	28.81	28.81
Absolute Stack Pressure, Ps = Pbar + Pg/13.6	Ps	in. Hg.	29.89	29.89	29.89	29.89
Stack Gas Velocity Vs= 85.49*Cp*ASRdP*((Ts)/((Ps)*(Mw)))^0.5	Vs	ft/sec	38.03	37.93	36.33	37.43
Vsm = 0.3048* Vs	Vsm	m/sec	11.59	11.56	11.07	11.41
Actual Stack Gas Flow Rate, Qa = 60*Vs*As	Qa	acf/min	9,411.6	9,387.4	8,992.0	9,263.7
Stack Gas Flow Rate (STP), Qsw = 528/29.92 * Qa * (Ps/Ts)	Qsw	scf/min	4,374.6	4,361.7	4,180.0	4,305.4
Dry Stack Gas Flow Rate (Dry, STP),	Qsd	dscf/min	4,133.3	4,121.1	3,949.4	4,067.9
Qsd = 528/29.92 * Qa * (1-Bws)* (Ps/Ts)		dscm/min	117.0	116.7	111.8	115.2

Sampling Data Summary

Parameter	SYMBOL	UNITS	Run 7	Run 8	Run 9	3-RUN AVG.
Total Sampling Time	min	minutes	60	60	60	60
Stack Gas Oxygen Content	O_2	%	13.6	13.6	13.6	13.6
Stack Gas Carbon Dioxide Content	CO_2	%	5.6	5.6	5.6	5.6
Gas Sample Volume at Standard Conditions,	Vm(std)	cu. ft.	34.332	34.533	46.609	38.492
		cu. m.	0.972	0.978	1.320	1.090
Dry Stack Gas Flow Rate (Dry, STP),	Qsd	dscf/min	4,133.3	4,121.1	3,949.4	4,067.9
		dscm/min	117.0	116.7	111.8	115.2

Vidar Viking

Function: Secondary Icebreaker

Ship Dimensions
Length: 83.7 m
Width: 18.0 m
Propulsion: (2) MaK 8M32C (3,840 kW each)
(2) MaK 6M32C (2,880 kW each)
Reference: Vessel Specifications

Stack Parameters (propulsion engines)
Height: 28.96 m
Diameter: 0.70 m
Velocity: 24.9 m/sec @ 80% load
Temperature: 579 K @ 80% load
References: Project Guide for MaK M32C engines
Stack test of same engine type on Tor Viking II - 5/18/2007

LATEST NEWS

15.12.2008 15:41:58
The partners in Trans Viking agree to divide ownership

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Sponsoring the local rescue service

08.09.2008 13:45:56
Viking scores high on FPAL

04.07.2008 10:07:49
Vessels being fitted with new secondary winches

News Archive

AHTS/Icebreaker Vidar Viking - Main Characteristics

Design :
KMAR 808 AHTS/ ICEBREAKER (Now; MOSSMAR)

Classification :
DnV,+1A1, SUPPLY VESSEL, SF, TUG, ICEBREAKER ICE-10, DK(+) EO HELDK-SH DYNPOS-AUTR HL(2,8) W1-OC

Built / Delivered :
Havyard Leirvik, Norway - 02//2001 - IMO 9199646

Registered / Flag :
Skärhamn, Swedish

Owners :
Trans Viking Icebreaking & Offshore AS , Kristiansand, Norway

Commercial Managers :
Viking Supply Ships A/S, Kristiansand, Norway

Dimensions
Length Over All (LOA) : 83.70 metres
Length between p.p. : 75.20 metres
Breadth, moulded : 18.00 metres
Depth, moulded : 8.50 metres
Draught (scantling) : 7.20 metres
Draught (design) : 6.00 metres
Freeboard (design) : 2.50 metres

Tonnage
Dead Weight : 2,528 tonnes
Light Ship : 4,289 tonnes
Gross : 3,382 tonnes
Net : 1,145 tonnes

Capacities
Dry Bulk : 283 m 3 in 4 tanks - totalling 10,000 ft 3
Pot Water : 724 m 3
Drill Water / Ballast : 1,113 m 3
Brine : 400 m 3 – SG 2.5
Oil Based Mud : 657 m 3 – SG 2.8
Base Oil : 242 m 3
Fuel Oil : 1,190 m 3 Marine Gas Oil (Diesel)
Urea : 94 m 3
Diesel Overflow : 21 m 3 with alarm
Diesel Service / Settling : 2 x 20 m 3
Deck Load : Abt 1,350 ts
Deck Area : 603 m 2 / 40.20 m x 15.0 m
All products in dedicated tanks – no dual purpose tanks

Discharge Rates / Lines etc.
Dry Bulk : 2 x 25 m 3/h compressors – 80 psi. Two separate discharge systems.
Discharge rate 2 x 75 m 3 / h at 90 metres head
Pot Water : Discharge rate 1 x 250 m 3 / h at 9 bar
Drill Water / Ballast : Discharge rate 1 x 250 m 3 / h at 9 bar
Brine : Discharge rate 2 x 75 m 3 / h at 18 bar
Oil Based Mud : Discharge rate 2 x 75 m 3 / h at 24 bar - Oil Mud Agitators fitted
Base Oil : Discharge rate 1 x 75 m 3 / h at 9 bar
Fuel Oil (Diesel) : Discharge rate 1 x 250 m 3 / h at 9 bar
Discharge Stations : All products mid and aft both SB and PS
Discharge Lines : 6 inch Weco system with reducers for Pot / Drill Water, Fuel Oil and Dry Bulk : 5 inch Weco system with reducers for Brine, Base Oil and Oil Base Mud
Tank cleaning : Mud and Base Oil tanks fitted with permanent tank cleaning system and heating
Flow Meters : Flow meters fitted for Pot Water and Fuel Oil (Digital display + printer for MGO)

Propulsion
Main Engine : MAK 18,300 BHP - 4 eng (father/son) 2 x 3,840 kW + 2 x 2,880 kW = 13,440 kW
Thrusters : Bow 1,200 BHP in tunnel (Electr) + 1,200 BHP 360 deg retractable = 2,400 BHP : Stern 1,200 BHP in tunnel (Electrical)
Propellers : 2 KaMeWa 4 blades in nozzles – Dia about 4.0 meter
Rudders : 2 spade rudders

Bollard Pull
Bollard Pull : 205 continuous (DnV certified) / Abt. 210 max pull

Speed/Consumption
Speed/Consumption : 16 knots – Abt. 42.7 MT / 24 hrs at 6.0 meter draught
: 12 knots – Abt. 15.6 MT
: 10 knots – Abt. 8.6 MT

Towing & Anchorhandling Equipment
AHT Winch : Brattvaag towing/anchorhandling winch 400 ts pull / 550 ts brake holding cap

CONTACT US

Viking Supply Ships AS
Kirkegaten 1
P.O Box 204
N - 4662 KRISTIANSAND
NORWAY

Ph: **+47 38 12 41 70**

AHT Drum : One of 1,400 mm dia. x 3,750 dia x (1,250 mm + 1,250 mm) length
Wire Capacity : 2 x 1,900 m of 77 mm wire or 2 x 1,650 m of 83 mm wire
AH Drum : One of 1,400 mm dia. x 3,750 mm dia. x 3,000 mm length
Wire Capacity : 4,100 m of 83 mm wire
Winch Control : TOWCON 2000 Automatic Control with printer
Pennant Reels/Caps : One of 2 x 1,500 metres of 77 mm wire or 2 x 1,300 metres of 83 mm wire : One of 6,700 metres of 77 mm wire or 5,580 metres of 83 mm wire – 72.0 ts pull
Alt Fibre Rope Capacity : 1,000 m of 190 mm fibre rope
Large Reel Inner Core : 1,500 mm dia
Cable Lifters : 2 x 76 mm and 2 x 84 mm onboard
Chain Lockers : 2 x 129 m3 / giving abt 2 x 6,000 ft of 3 inch chain
Shark Jaws : 2 pairs of Karm Forks arranged for chain up to 165 mm dia / 750 ts SWL
Inserts for handling for 65, 75, 85, 100, and 120 mm dia. wire/chain
Stern Roller : One of 3,5 m dia. x 6.0 m length – SWL 500 ts
Guide Pins : 2 pairs of Karm Fork Hydraulic pins – SWL 170 ts

Workwires
Work Wire : 300 metres of 77 mm dia
Chaise Wire : 1,000 metres of 83 mm dia
Main Tow Wire : 1,500 metres of 83 mm dia
Spare Tow Wire : 1,300 metres of 83 mm dia

Deck Equipment
Capstans : 2 x 15 ts pull
Tugger Winches : 2 x 15 ts pull
Smit Brackets : One bracket on B Deck FW – SWL 250 ts
Cranes : 1 hydraulic crane on forep cargo deck giving 6 / 12 ts at 20/10 m arm (360 degr)
: 1 telescopic crane on aft cargo deck giving 1.5 / 3 ts at 15/10 m arm (360 degr)
: 1 hydraulic crane on fore-castle deck for stores etc
Windlass : 1 hydraulic windlass / mooring winch. Two de-clutchable drums 46 mm K3 chain

Accommodation
Accommodation for a total of 31 persons, including crew.
All accommodation equipped with air-condition and humidification facilities.

Dynamic Positioning
The vessel is equipped with Kongsberg Simrad SDP 21 Redundant DP System - GreenDP

Misc .
We would like to highlight the exceptional good manoeuvrability of the vessel. Also please note the environmental bonus using M/V "Vidar Viking" due to her exceptional low noise level, and the installed Exhaust Gas Treatment Systems (Catalyst), effectively reducing the NOx levels. M/V"Vidar Viking" is also equipped with diesel overflow tank with alarm system. The vessels design, and her possibility for running 2 engines, ("father/son") gives favourable fuel consumption.

Furthermore, we will highlight the vessels DynPos system, the new Kongsberg Simrad design; GreenDP which is new concept for fuel tight DP. GreenDP is environment friendly and reduces fuel consumption significantly, and reduces wear and tear of thrusters and diesels due to very smooth control actions. GreenDP also increase the operational reliability of the vessel.

Particulars believed to be correct, without guarantee.

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